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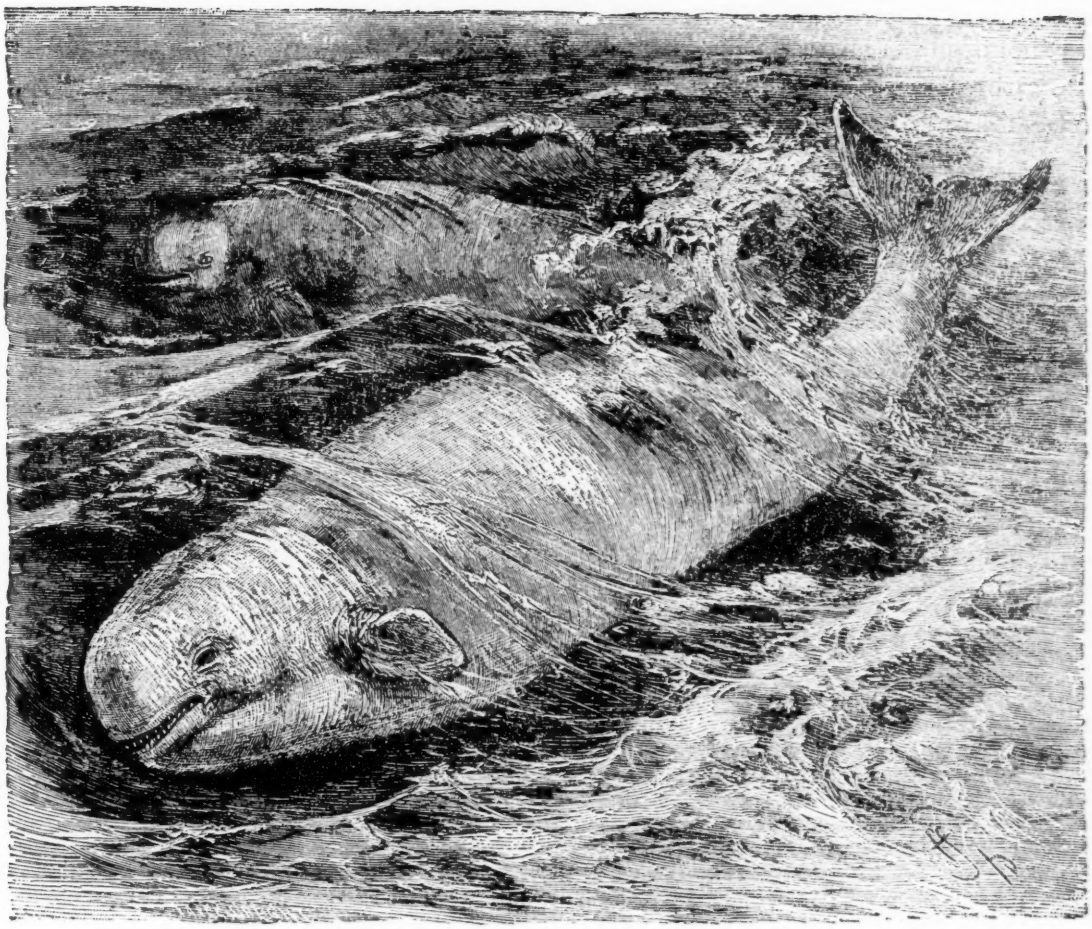

Beluga Whales

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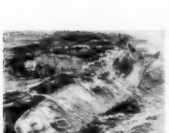

On the cover:
An early engraving depicting two belugas, *Delphinapterus leucas*.

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Cook Inlet Belugas, *Delphinapterus leucas*: Status and Overview

SUE E. MOORE and DOUGLAS P. DEMASTER

Introduction and Background

Of the five populations of beluga, *Delphinapterus leucas*, in Alaska, the most isolated is the one in Cook Inlet (Hazard, 1988; Hill and DeMaster, 1998) (Fig. 1). The geographic and genetic segregation of this stock (O'Corry-Crowe et al., 1997), combined with the beluga's tendency toward site fidelity in summer, makes this population especially vulnerable to impacts from large or persistent harvests.

Results from 8 years (1993–2000) of summer aerial surveys by NOAA's National Marine Fisheries Service (NMFS) and a review of previous studies have indicated that the beluga distribution within Cook Inlet was shrinking between the 1970's and mid 1990's (Rugh et al., 2000), and from 1994 to 1998 the abundance declined by nearly 50% (Hobbs et al., 2000a). The average reported harvest of belugas in Cook Inlet during this period, about 72 whales per year (Mahoney and Shelden, 2000), was 21% of the best estimate of abundance in 1998 (347 whales, SE = 101, CV = 0.29)(Hobbs et al., 2000a). Relative to the total number of animals that can be safely removed annually from a population of marine mammals (defined as the potential biological removal (PBR) level in the Marine Mammal Protection Act (MMPA) (16 U.S.C. 1362 § 20)), the reported harvest rate was about 5 times the calculated PBR of 14 whales (Hill and DeMaster, 1998).

The Alaska Scientific Review Group (AKSRG)[1], the Alaska Beluga Whale Committee (ABWC)[2], the Cook Inlet Marine Mammal Council (CIMMC)[3], various NMFS offices (in particular the NMFS Alaska Regional Office (AKR), NMFS Office of Protected Resources (OPR), and the NMFS National Marine Mammal Laboratory (NMML)), and several nongovernmental organizations (NGO's), have all expressed concern about the high level of harvest from this small, isolated population of belugas (NMFS, 1999, 2000). In a strongly worded statement to the NMFS and the Marine Mammal Commission, the AKSRG concluded that "the Cook Inlet beluga situation is one of the most pressing conservation issues facing Alaskan marine mammals at this time."[4]

Accordingly, NMFS, which the MMPA charges with management and protection of belugas in Alaska, initiated a formal review of the status of the Cook Inlet beluga stock on 19 Nov. 1998 (NMFS, 1998). This was through a cooperative process with ABWC and CIMMC. The objective of this review was to provide recommendations to NMFS AKR and OPR regarding the classification of this stock as endangered or threatened under the Endangered Species Act (ESA) or depleted under the MMPA.

The status review coincided with workshops held by the ABWC (16–17 Nov. 1998) and AKSRG (18–20 Nov. 1998) in Anchorage, Alaska. These workshops provided a forum for scientific presentations to interested parties, such as hunters, administrators, and researchers. To insure that the review was comprehensive and based on the best available data, NMFS subsequently solicited information and comments from any interested persons or groups/organizations on Cook Inlet beluga status. Comments were received from 19 Nov. 1998 through 19 Jan. 1999, followed by a public workshop held in Anchorage on 8–9 Mar. 1999. This provided a public review of relevant scientific information and an additional avenue for the public to comment on these issues.

The scientific portion of these reviews focused on the current status of Cook Inlet belugas: distribution, abundance, trends in abundance, habitat use, and contaminant burdens. The effects of the Alaska Native subsistence harvest and the potential effects of other anthropogenic impacts, as well as beluga natural mortality, were also examined and are summarized below.

Cook Inlet Beluga Summary

Distribution and Abundance

Beluga distribution in Cook Inlet, based on sightings made during aerial

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[1] In 1994, the MMPA was amended to require the establishment of regional scientific review groups (SRG's). These groups assist the Secretary of Commerce with drafting stock assessments for marine mammal stocks that occur in waters under U.S. jurisdiction.

[2] Founded in 1988, the ABWC is a group of beluga whale hunters, researchers, and governmental agency representatives from Alaska and northern Canada (Adams et al., 1993). Today the group comanages western Alaska beluga stocks (excluding Cook Inlet) under a cooperative agreement with NMFS.

[3] In 1994, a group of beluga hunters in Anchorage joined together to form the CIMMC. NMFS entered into an interim cooperative agreement with CIMMC to comanage the Cook Inlet beluga stock from 23 May to 31 December 2000.

[4] Letter dated 27 July 1998 from Lloyd Lowry, Chair, AKSRG, to Dan Alex, Chair, CIMMC.

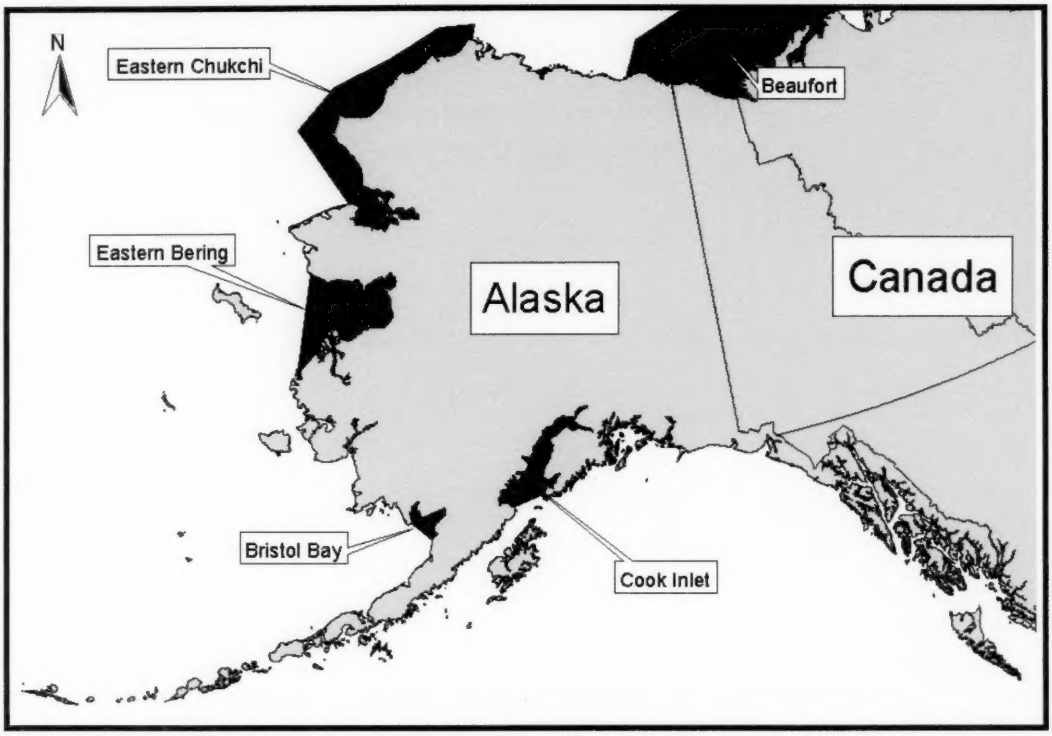

Figure 1.—Beluga stocks found in Alaska waters.

surveys flown annually during June and/or July of 1993–2000, is presented in Rugh et al. (2000). These surveys provide a thorough, annual coverage of the coastal areas of the inlet (1,350 km of shoreline) and include roughly 1,000 km of transect surveys across the central inlet.

Each year, belugas were found in a few shallow-water areas near river mouths in upper Cook Inlet. The largest concentration (151–288 whales by aerial count) was in the Susitna River Delta and/or in Knik Arm. A smaller group (17–49 whales) was consistently found between Chickaloon River and Point Possession. Smaller groups (generally <20 whales) occasionally occurred in Turnagain Arm, Kachemak Bay, Redoubt Bay (Big River), and Trading Bay (McArthur River) prior to 1995 but not thereafter.

Comparing the distribution of belugas in the late 1970's with that in the 1990's shows that there has been a consistent decline in sightings both in offshore areas and in lower Cook Inlet, suggesting that the range of this stock is shrinking (Rugh et al., 2000). This contention is supported by many anecdotal reports (Speckman and Piatt, 2000; Huntington, 2000; Rugh et al., 2000) and the absence of beluga sightings during dedicated at-sea surveys for marine birds and mammals conducted in lower Cook Inlet in late July and early August 1995–99 in an area where the whales used to be fairly common (Speckman and Piatt, 2000). These small boat surveys, which covered a total of 6,249 linear km in both nearshore and offshore habitats, found no belugas among 791 individual sightings representing 10 species.

Annual abundance estimates of Cook Inlet belugas were calculated for 1994–2000 (Hobbs et al., 2000a), based on counts made by aerial observers (Rugh et al., 2000) that were corrected for group sizes estimated from video recordings (Hobbs et al., 2000b). Point estimates of annual abundance ranged from a high of 653 (CV = 0.43) whales in 1994, to a low of 347 (CV = 0.29) whales in 1998; abundance in 2000 was 435 whales (CV = 0.23; 95% CI = 270–679)(Hobbs et al., 2000a). Monte Carlo simulations indicate a 47% probability that from June 1994 to June 1998, abundance of the Cook Inlet stock of belugas declined 50%, after which the decline may have stopped (Hobbs et al., 2000a).

To address concerns that summer surveys of Cook Inlet alone did not account for the full range of this stock, possible beluga distribution in the Gulf of Alaska was examined through a review of surveys conducted as far back as 1936 (Laidre et al., 2000). More than 150,000 km of dedicated survey effort in the Gulf of Alaska since 1975 resulted in sightings of over 23,000 cetaceans, only 5 of which were belugas. To date, there have been only 34 beluga sightings out-

side of Cook Inlet: 9 near Kodiak Island, 10 in or near Prince William Sound, 14 in Yakutat Bay, and 1 anomalous sighting well south of the Gulf near Tacoma, Washington. In addition, commercial whaling records for the years 1907–39 show belugas were taken only in Cook Inlet and not in the Gulf of Alaska, nor is there any conclusive evidence of beluga remains in archaeological sites outside Cook Inlet. Thus, there are no records of large, persistent groups of belugas in the Gulf of Alaska other than in Cook Inlet.

Habitat Associations and Contaminants

Habitat associations for Cook Inlet belugas were reviewed to complement population assessment surveys during 1993–2000 (Moore et al., 2000). Beluga summer distribution (Rugh et al., 2000) was used to delineate areas of high (Region 1), moderate (Region 2), and low (Region 3) whale concentrations in Cook Inlet. Subsequently, physical, ecosystem, and anthropogenic habitat factors were summarized from available literature and tabulated for each region.

In general, belugas congregate in shallow, relatively warm, low-salinity water near major river outflows in upper Cook Inlet during summer (defined as their primary habitat), where prey availability seems comparatively high and predator occurrence relatively low. In winter, belugas are seen in the central inlet, but sightings are fewer in number and whales are more dispersed compared to summer.

Although sewage effluent, discharges from industrial and military activities, and possibly natural catastrophic events such as floods negatively affect water quality in the inlet, analyses of organochlorines and heavy metal burdens indicate that Cook Inlet belugas are not assimilating contaminant loads greater than any other Alaska stocks (Becker et al., 2000). Much of the available information on Cook Inlet habitat is descriptive in nature and could be greatly improved by integration of quantifiable habitat measures associated with beluga occurrence. Recommendations in Moore et al. (2000) include: 1) obtaining seasonal data on fish run numbers for rivers used by belugas, and 2) measuring anthropogenic factors (such as fishery bycatch and underwater noise) within and outside beluga whale concentration areas.

Tissue samples from three different Alaska stocks of belugas (Beaufort Sea, eastern Chukchi Sea, and Cook Inlet) collected from subsistence harvests were analyzed for contaminants (Becker et al., 2000). Blubber of animals from these stocks contained polychlorinated biphenyl (PCB) congeners, DDT, chlordane compounds, hexachlorobenzene (HCB), dieldrin, mirex, toxaphene, and hexachlorocyclohexame (HCH). Cook Inlet belugas had the lowest concentrations of DDT (1.35 ± 0.73 and 0.59 ± 0.45 mg/kg in males and females, respectively) and PCB (1.49 ± 0.70 and 0.79 ± 0.56 mg/kg wet mass in males and females, respectively) of all three stocks. DDT and PCB concentrations in the blubber of male belugas in Cook Inlet was half that found in males in the Alaska Arctic and an order of magnitude lower than in animals from the St. Lawrence Estuary, Canada. Liver concentrations of cadmium and mercury (<1 mg/kg and 0.704–11.42 mg/kg wet mass, respectively) were also lower in the Cook Inlet stock, but copper levels (3.97–123.8 mg/kg wet mass) were substantially higher in Cook Inlet animals, compared to Alaska Arctic animals, and were similar to those reported for Hudson Bay, Canada, belugas. Although total mercury levels were lowest in the Cook Inlet stock, methyl mercury concentrations were similar among all three stocks (0.34–2.11 mg/kg wet weight).

VHF Radio and Satellite Tagging

VHF radio transmitters were attached to Cook Inlet belugas with suction cups in 1994 and 1995 to characterize beluga surfacing behavior (Lerczak et al., 2000). Video recordings were also made to document behavior of undisturbed whales and whales actively pursued for tagging. Eight whales were successfully tagged, and five tags remained attached for over 1 h each. Mean dive interval was 24.1 sec (SD = 6.4 sec). Videotaped behaviors were categorized as "head-lifts" or "slow-rolls." In undisturbed beluga groups, surfacing intervals were significantly different between head-lifting ($\bar{x}$ = 1.02 sec, SD = 0.38 sec, n = 28) and slow-rolling whales ($\bar{x}$ = 2.45 sec, SD = 0.37 sec, n = 106). Undisturbed juveniles exhibited shorter slow-roll surfacing intervals ($\bar{x}$ = 2.25 sec, SD = 0.32 sec, n = 36) than adults ($\bar{x}$ = 2.55 sec, SD = 0.36 sec, n = 70). Belugas did not exhibit strong reactions to suction-cup tags. This tagging method shows promise for obtaining surfacing data on individual belugas over periods of several days.

Attempts to capture and place satellite tags on belugas in Cook Inlet were conducted during late spring and summer of 1995, 1997, and 1999 (Ferrero et al., 2000). In 1995, efforts to capture belugas with a hoop net proved impractical in Cook Inlet because the waters were too turbid to see a whale underwater. In 1997, capture efforts focused on driving belugas into nets. Although this method had been successful in the Canadian High Arctic, it failed in Cook Inlet due to the ability of belugas to detect and avoid nets in shallow water. In 1999, belugas were successfully captured using a net encirclement technique. A satellite tag was attached to a juvenile male and provided first-ever documentation of beluga movements within Cook Inlet. This animal remained in the northern region of Cook Inlet throughout the period (31 May–17 Sept.) that it was tracked via satellite (Ferrero et al., 2000).

Harvest History and Traditional Knowledge

Archeological studies show that prehistoric Alutiiq Eskimos and Dena'ina Athabaskan Indians used many marine resources in Cook Inlet, including belugas (Mahoney and Shelden, 2000). Commercial whaling and sport hunting occurred periodically in Cook Inlet during the 1900's before such activities were banned by the MMPA in 1972. The decline of the Cook Inlet stock, and its subsequent designation as depleted under the MMPA has, in part, been attributed to harvesting by Alaska Native subsistence hunters. It is difficult to obtain accurate estimates for Alaska

Native beluga harvests in Cook Inlet due to the inability to identify all of the hunters and, in turn, the size of the harvest. So, while definitive harvest statistics are unavailable, it does appear that 21–147 belugas were taken annually by Alaska Native hunters between 1994 and 1998 (Mahoney and Shelden, 2000). Similar removals may also have occurred in earlier years.

Concerns about the decline of the Cook Inlet stock and its continued exploitation led to the voluntary suspension of the subsistence hunt by Alaska Natives in 1999, and the MMPA was subsequently amended (P.L. 106–554) to require a cooperative agreement between NMFS and Alaska Native organizations before hunting could be resumed. In October 1999, NMFS established marking and reporting regulations to improve harvest monitoring.

From October 1998 to March 1999, beluga hunters in Cook Inlet took part in a traditional ecological knowledge (TEK) survey (Huntington, 2000). Traditional knowledge about belugas has been documented for other Alaska beluga stocks (Huntington and Mymrin, 1996; Huntington, 1998), and the same interview-based methods were used to gather information systematically concerning the natural history of belugas in Cook Inlet. The hunters' knowledge is largely consistent with that described from scientific research, and it extends and augments published descriptions of the ecology of this isolated stock. Publication of this information and involving the Native hunters to a greater extent in research and management are important contributions to the conservation of Cook Inlet belugas.

Acknowledgments

Funding for most projects described in this collection of articles was provided to the NMFS National Marine Mammal Laboratory (NMML) by the NMFS Marine Mammal Assessment Program, as well as through funds and logistical support from the NMFS Alaska Regional Office (AKR). The CIMMC and ABWC provided support for tagging operations and workshops. R. Hobbs was the Task Leader for projects conducted through the NMML.

Aerial surveys were piloted by T. Blaesing of Commander NW, Ltd., each year during 1993–96, and by D. Weintraub during 1998–2000. In 1997, the pilots were J. Hagan and J. Longenecker from NOAA's Aircraft Operations Center. Primary aerial observers from NMFS were R. Angliss (1994–95), D. DeMaster (1994–95), R. Hobbs (parts of 1993 and 1996–99), L. Litzky (1998–2000), B. Mahoney (1993–96, 1998–2000), D. Rugh (1993 and project leader 1994–2000), K. Shelden (1993, 1995–2000), J. Waite (1996–97), and D. Withrow (project leader in 1993). Other NOAA/ADFG observers were J. Hanson (1993), J. Lewis (1993), B. Smith (1993 and 1999), and S. Thumm (1993).

Representatives of CIMMC joined the aerial team on one or more survey days in 1995 (K. Andrews, J. Dizon, D. Calcote, and R. Cassidy), 1996 (M. Lamoreaux), 1997 (J. Blatchford), 1998 (E. Paniptchuk, G. Paniptchuk, C. Eben, and F. Anawrok), 1999 (D. Alex, P. Blatchford [Alaska Native Marine Mammal Hunters Committee, ANMMHC], P. Merryman [Native Village of Tyonek], and J. Blatchford [ANMMHC]), and 2000 (L. Green, P. Dimmick, D. Alex, F. Kakaruk, and G. Paniptchuk). The ABWC and NMFS AKR provided partial support for some of the CIMMC observers. Analysis of the video tapes collected during the aerial surveys was done by L. Baraff, R. Bush, S. Harkness, L. Litzky, M. Muto, S. Norman, K. Shelden, and J. Waite (leader). Aerial surveys were conducted under NMFS Scientific Research Permits No. 791 (P771#63) and No. 782-1360.

Participants in the tagging projects included representatives from NMFS, USFWS, CIMMC, and scientific consultants: R. Hobbs (project director), A. Andriolo, J. Cesarone, D. DeMaster, G. Dimmick, R. Dimmick, L. Dugan, M. Eagleton, C. Eben, R. Ferrero (leader in 1999), B. Hanson, S. Hill, M. Lamoreaux, J. Lerczak, L. Litzky, B. Mahoney, P. Nader, A. Nuglene, G. O'Corry-Crowe, D. Owens, D. Rugh, D. Seagars, M. Saccheus, K. Shelden, T. Smith, S. Thumm, R. Tocktoo, D. Vos, J. Waite, and W. Walker. Special thanks go to R. Morris for providing advice, personnel, and equipment. Additional support and equipment for oceanographic sampling was provided by B. Reilly and O. Smith (U.S. Army Corps of Engineers-Anchorage) and K. Krogflund (Univ. of Washington-School of Oceanography). J. Lerczak and J. Waite reviewed the audio tapes of surfacing interval data from suction cup tagged whales. The suction cup tagging project was conducted under NMFS Permit No. 897, and the satellite tagging project was conducted under NMFS Permit No. 957.

The vessel-based study of lower Cook Inlet was directed by the Interior Department's U.S. Geological Survey (USGS). Additional funding for the project was provided by the Exxon Valdez Oil Spill Trustee Council (Restoration Project 00163M) and the Minerals Management Service (MMS). Observers during the study included: J. Figurski, B. Keitt, G. Drew, G. Snedgen, T. van Pelt, M. Robards, M. Arimitsu, B. Congdon, S. Zador, A. Harding, A. Kitaysky, C. Lascink, V. Lodha, D. Ruthrauff, R. Seymour, K. Hobson, A. Abookire, R. Suydam, and S. Wright. Thanks go to the captains and crews of the R/V *Pandalus*, P. Desjardins, and M. Hottman, Captain K. Bell of the R/V *Tiglax*, and G. Snedgen of the R/V *David Grey*.

Participants in the TEK study included P. Blatchford, H. Dimmick, R. Dimmick, C. Eben, C. Jack, F. Mamaloff, L. Saccheus, R. Schaeffer Sr., and two hunters who wished to remain anonymous. Funding and support was provided by ABWC, funds were administered by North Slope Borough, CIMMC helped set up interviews, and NMFS helped with all aspects of the project. In particular, help was provided by: D. Alex, D. Carr, M. Adams Carroll, K. Frost, C. Jack, J. James, B. Mahoney, S. Rudolph, C. Saccheus, R. Schaeffer, Lee Stephan, Leo Stephan, and B. Takes Horse.

The contaminants study received funding and support from USGS, MMS, NMFS, and ABWC. Samples from Cook Inlet were collected by NMFS, AKR, and ages were determined by B. Mahoney and R. Suydam. Tissue samples are maintained in the Alaska Marine Mammal Tissue Archival Project (AMMTAP), a collaboration between

USGS, NMFS, and the National Institute of Standards and Technology.

Life history data on harvested whales were collected by NMFS AKR in cooperation with Alaska Native hunters. Ages of animals were determined by B. Mahoney. Harvest statistics were provided by CIMMC, ABWC, ADFG, and Native hunters of Cook Inlet.

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Distribution of Belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, During June/July 1993–2000

DAVID J. RUGH, KIM E. W. SHELDEN, and BARBARA A. MAHONEY

Introduction

Belugas, *Delphinapterus leucas*, inhabit most of the Northern Hemisphere's Arctic and subarctic seas (Gurevich, 1980). In U.S. waters in the summer, they are distributed around much of mainland Alaska from the Gulf of Alaska to the Beaufort Sea (Hazard, 1988), and five discrete stocks are recognized, depending on their summer location: Cook Inlet, Bristol Bay, Norton Sound, the eastern Chukchi Sea, and the Beaufort Sea (O'Corry-Crowe et al., 1997).

The most isolated is the Cook Inlet stock, separated from the others by the Alaska Peninsula (>900 km long), with virtually no whales reported between Cook Inlet and the nearest stock in Bristol Bay (Laidre et al., 2000). Belugas in Cook Inlet are concentrated in the northern reaches of the inlet, at least during the spring (Huntington, 2000; Calkins[1]), and their natal homing behavior may have kept them separated from other beluga stocks long enough to effect evolutionary differentiation (O'Corry-Crowe et al., 1997).

The geographic isolation of these whales, in combination with their site fidelity, makes this stock vulnerable to impacts from large or persistent harvests by Alaska Natives (Hill, 1996) and anthropogenic environmental hazards (Moore et al., 2000; Calkins[2]). A very similar situation has occurred in the St. Lawrence River in eastern Canada, where a small, isolated stock of belugas suffered an intense harvest in the past without leaving the area, and it is now vulnerable to anthropogenic contaminants (Kingsley, 1998). Remarkable site tenacity despite hunting pressure was also demonstrated by belugas in a study conducted by Caron and Smith (1990) in eastern Hudson Bay, Canada.

Concern for the management of the Cook Inlet stock led to a project begun in 1993 with funding from the Marine Mammal Assessment Program of the National Oceanic and Atmospheric Administration (NOAA). This project was conducted by NOAA's National Marine Mammal Laboratory (NMML), Alaska Fisheries Science Center, National Marine Fisheries Service (NMFS), in cooperation with the NMFS Alaska Regional Office, the Alaska Beluga Whale Committee (ABWC), and the Cook Inlet Marine Mammal Council (CIMMC, which was established in 1994).

Basic to the assessment of the Cook Inlet stock was the documentation of the distribution and abundance of these whales. Aerial surveys are the established method for collecting these data (e.g. Calkins[1]; Klinkhart[3]; Murray and Fay[4]). Accordingly, the objectives of our

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ABSTRACT—Aerial surveys of belugas, Delphinapterus leucas, *in Cook Inlet were flown each year during June and/or July from 1993 to 2000. This project was designed to delineate distribution and collect aerial counts, elements critical to the management of this small, isolated stock that was subjected to a persistent harvest by Native hunters. The surveys provided a thorough, annual coverage of the coastal areas of the inlet (1,350 km of shoreline) and included roughly 1,000 km of offshore transects annually. Coastal transects were flown 1.4 km from the waterline, thus surveying most of the area within 3 km of shore. These, along with offshore transects, provided annual systematic searches of 13–33% of the entire inlet. The largest concentration of belugas (151–288 whales by aerial count) was in the northern portion of upper Cook Inlet in the Susitna River Delta and/or in Knik Arm. Another concentration (17–49 whales) was consistently found between Chickaloon River and Point Possession. Smaller groups (generally <20 whales) were occasionally found in Turnagain Arm, Kachemak Bay, Redoubt Bay (Big River), and Trading Bay (McArthur River) prior to 1995 but not thereafter. Over the past three decades, summer distribution has shrunk such that sightings now only rarely occur in lower Cook Inlet and in offshore areas. In the 1990's, most (96–100%) of the sightings were concentrated in a few dense groups in shallow areas near river mouths in upper Cook Inlet.*

[1] Calkins, D. G. 1984. Belukha whale. Vol. IX of Susitna hydroelectric project; final report; big game studies. Alaska Dep. Fish Game. Doc. 2328, 17 p.

[2] Calkins, D. G. 1983. Marine mammals of lower Cook Inlet and the potential for impact from Outer Continental Shelf oil and gas exploration, development, and transport. Research Unit 243; Final Rep. of Principal Investigators, Outer Continental Shelf Environ. Assessment Program, U.S. Dep. Commer., NOAA, Natl. Ocean Serv., Off. Oceanogr. Mar. Serv., Ocean Assessments Div. 20:171–263.

[3] Klinkhart, E. G. 1966. The beluga whale in Alaska. Alaska Dep. Fish Game, Juneau, Fed. Aid Wildl. Restor. Proj. Rep. Vol. VII, Proj. W-6-R and W-14-R, 11 p.

[4] Murray, N. K., and F. H. Fay. 1979. The white whales or belukhas, *Delphinapterus leucas*, of Cook Inlet, Alaska. Unpubl. pap. SC/31/SM12 pres. to Int. Whal. Comm. Sci. Committee, 7 p.

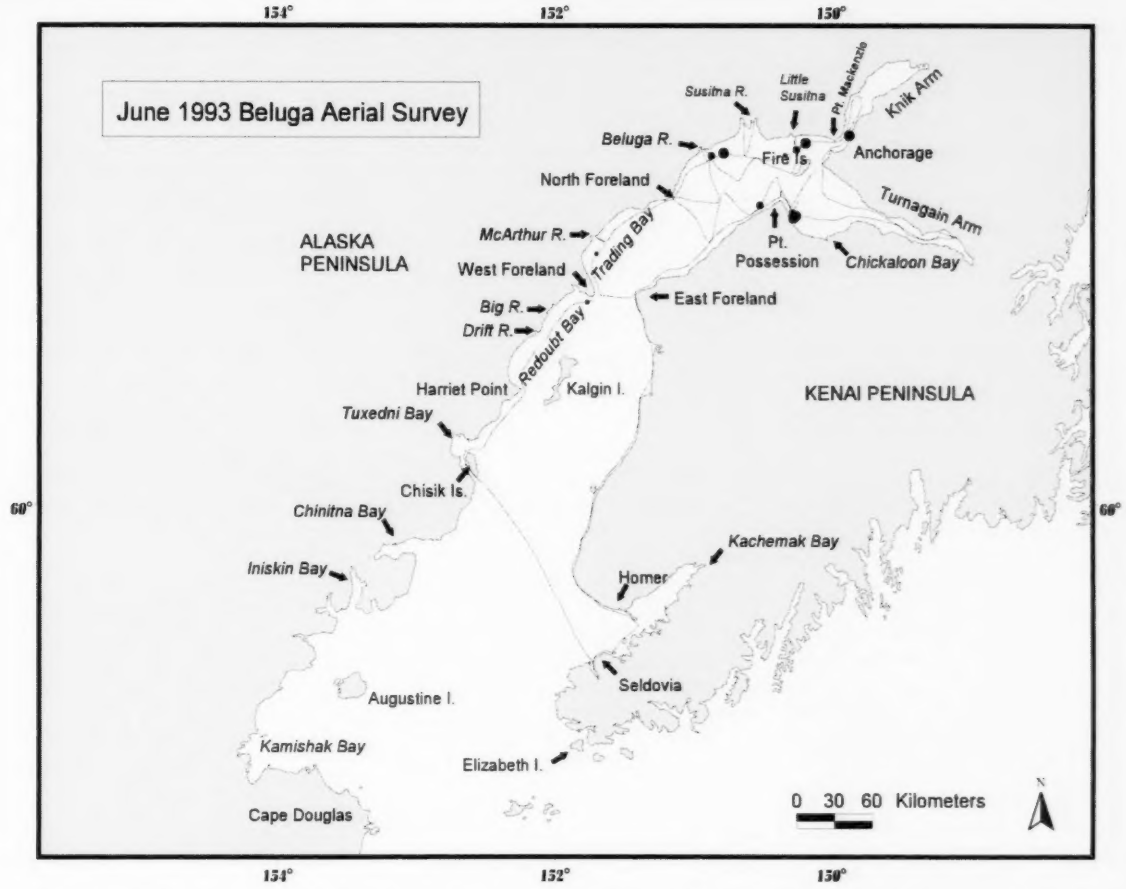

Figure 1.—Beluga groups seen 2–5 June 1993 during coastal and offshore aerial surveys of Cook Inlet, Alaska, with tracklines shown. In this and the subsequent maps, only one sampling from each area is represented, and poor viewing conditions were not included. Virtually all of the sightings were near shore or along the edge of mudflats in upper Cook Inlet, and 80% were between the Susitna Delta and Knik Arm.

field studies were to 1) make complete searches for belugas around the perimeter of Cook Inlet, 2) fly transects over the offshore waters of Cook Inlet, and 3) make systematic counts of belugas for aerial estimations of group sizes. Aerial survey procedures were refined from year to year, but the basic survey and counting methods were kept consistent.

The objectives of this paper are to: 1) describe distributional information on belugas in Cook Inlet during June/July, the optimal survey period (belugas outside the inlet are reported by Laidre et al. (2000)), 2) compare recent distributional data to data collected in previous surveys, and 3) provide group size estimates for calculations of stock size. Abundance estimates are presented in Hobbs et al. (2000a). These are based on summary counts from the aerial effort (reported here), in combination with correction factors using paired-observer effort (Hobbs et al., 2000b), video documentation (Hobbs et al., 2000b), and surfacing times of radio-tagged whales (Lerczak et al., 2000).

Methods

Study Area

The study area, Cook Inlet, is a major marine feature in south-central Alaska, covering approximately 20,000 km^2 with 1,350 km of shoreline. The boundaries of this study area include all waters in the inlet north of an imaginary line from Elizabeth Island to Cape Douglas (Fig. 1) where belugas could occur, including rivers, shoals, and mudflats where the water appeared to be deeper than about 1 m. An imaginary line between East and West Foreland (at lat. 60° 43′N) made a convenient break between upper and lower Cook Inlet. This provided a division of the inlet for comparisons to previous surveys. Anchorage, the largest city in Alaska, is in the northeastern portion of the inlet and served as a convenient base of operations for these aerial surveys. A descrip-

tion of beluga habitat in Cook Inlet can be found in Moore et al. (2000).

The extremely turbid inlet waters in areas where belugas occur means that the whales are visible only when at the surface, unlike in the clear waters of the Arctic where whales are sometimes visible well below the water surface when seen from an aircraft. The young, gray individuals are especially difficult to see in the brown water of Cook Inlet.

Survey Protocol

The survey aircraft used on most flights from 1993 to 2000 was an Aero Commander 680 FL[5] with twin engines, high wings, 10-h flying capability, and seating capacity for five passengers and one pilot. The June 1997 survey was flown in a DeHavilland Twin Otter, which was larger but had similar characteristics to the Aero Commander. Both aircraft had large bubble windows at the forward observer positions. An intercom system allowed communication among the observers (2 on the left and 1 on the right), data recorder, and pilot. After 1993, a selective listening control-device was installed to aurally isolate the observers, who were also visually isolated from each other. This allowed for paired, independent observations as a check of sighting rates (Hobbs et al., 2000b). Most observers had previous experience on many marine mammal projects prior to flying with these surveys, and a core team flew on the Cook Inlet surveys for 7–8 seasons (see Acknowledgments).

Position data were collected from the aircraft's Global Positioning System (GPS) interfaced with a laptop computer used to enter sighting data. Data entries included routine updates of time and location at 1-min intervals and manual entries of percent cloud cover, sea state (Beaufort scale), glare (for each observer), visibility (on the left and right), and each beginning and end of a transect leg. Visibility was categorized into 5 subjective classes graded from excellent to useless based on sea state, glare, available light, and the condition of the observation window (whether it had rain, fog, or reflections). When survey conditions were considered poor or useless, they were treated in the analysis as unsampled areas. Observer seating positions were recorded each time they were changed, generally every 1–2 h, to minimize fatigue.

Tides

Tide heights in Cook Inlet were highly variable across the full geographical range of these surveys. No attempts were made to synchronize the flights with the predicted low tide, except in the Susitna Delta, because large groups of whales were found there consistently. The major advantage to surveying at low tide was that the effective survey area was greatly reduced in large parts of upper Cook Inlet dominated by extensive tidal flats.

Coastal Surveys

Coastal surveys were designed to maximize opportunities for finding belugas in shallow, nearshore waters where they typically range in summer (Calkins[1]). These surveys were conducted on a trackline about 1.4 km from the waterline. The trackline distance from shore was monitored by using an inclinometer to keep the water's edge 10% below the horizon while the aircraft was at the standard altitude of 244 m (800 ft). We found this altitude and the 10% search area to be a good compromise between maximal visual range and optimal sighting cue size without resulting in any evident disturbance to the animals. Ground speed was generally 170–185 km/h (90–100 kn), the minimum safe flying speed. Coastal surveys included searches of 5–20 km up each prominent river until the water appeared to be less than 1 m deep, based on the appearance of rapids or riffles. Distances flown up rivers were considered adequate according to Native hunters who flew with this project (see Acknowledgments).

Offshore Transects

In addition to the coastal surveys, offshore transects were flown across the inlet in most years (depending on available funds). A sawtooth pattern of tracklines was designed to cross shore at points about 30 km apart starting from Anchorage and zigzagging to the southern limits of Cook Inlet, between Cape Douglas and Elizabeth Island (Fig.1–9). Observers searched primarily within 1.4 km of the aircraft, but viewing conditions were usually so good they allowed for searches well beyond that distance.

Circling Over Whales

After a group of belugas was found, it was flown over at perpendicular angles to determine the perimeters of the group. This provided an accurate location of the group for mapping as well as a measure of group density by later comparing the number of whales relative to the total area in which the group was found. Next, a series of straight-line aerial passes was made on either side of the group until one or two pairs of observers could make at least four good counts each. The pilot was directed to fly close enough to the whales to optimize counting conditions (while maintaining an altitude of 244 m) but far enough away to keep the entire group in view. On each aerial pass, time spent counting was synchronized among the observers and recorded to the second. These counts were kept confidential until the season was over. A video camera documented most counting passes over each group of whales; this provided images for later analysis (Hobbs et al., 2000b). The observation time averaged about 0.5 h per whale group. In Cook Inlet, belugas were usually very concentrated, generally making it easy to define each group; however, when there were loose aggregations of whales, groups were defined as a function of convenience for counting while circling over them. This usually meant all whales within 100 m of each other were treated as a group for counting purposes.

Analytical Methods

Aerial counts used in this report are the medians of all of the primary observers' median counts made during multiple passes over a group. The process of using medians instead of means or maximum numbers reduces the effect of outliers (extreme counts) and makes the results more comparable to other surveys which lack multiple passes over whale

[5] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

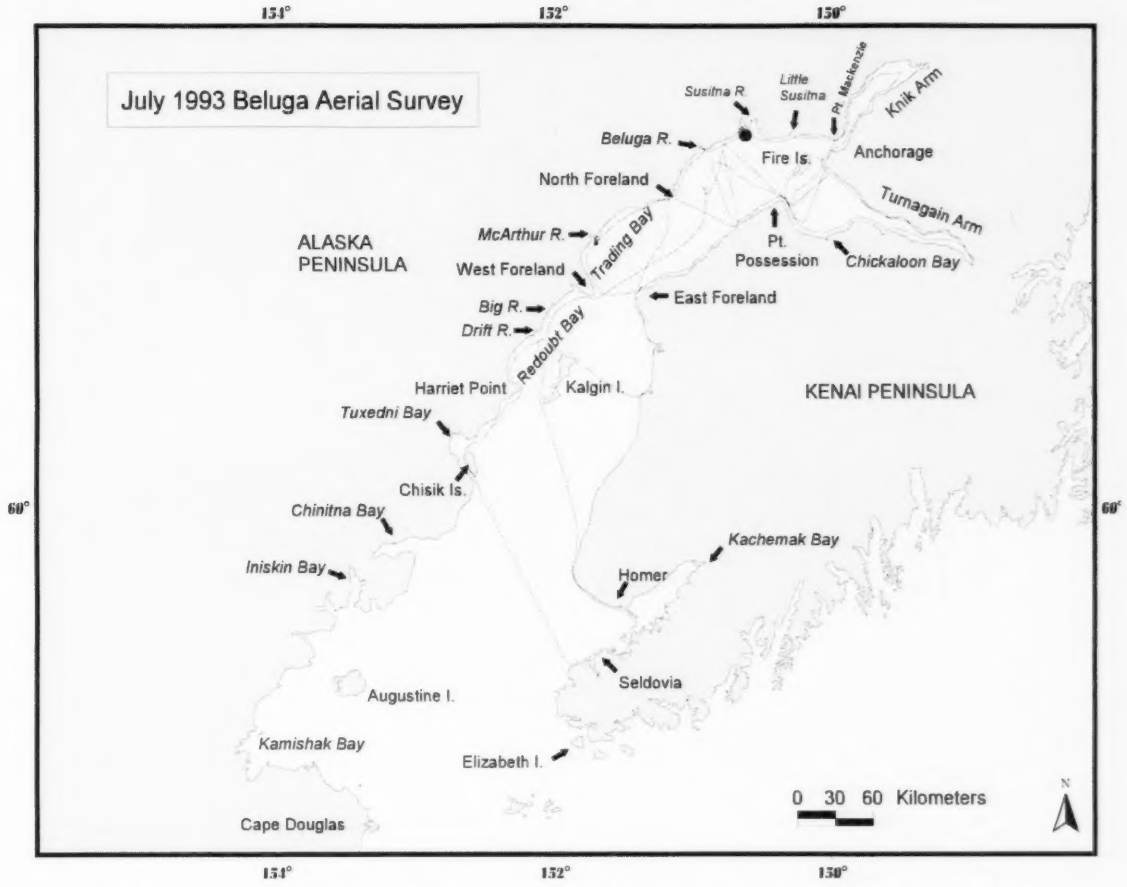

Figure 2.—Beluga groups seen 25–29 July 1993 during coastal and offshore aerial surveys of Cook Inlet. All of the sightings were near shore or along the edge of mudflats in upper Cook Inlet, and 82% were near the Susitna Rivers. (Only one day's sightings shown here.)

groups. The consistency of resightings between days, particularly of whales in the Susitna Delta and in Chickaloon Bay, allowed results to be combined between survey days, assuming whales did not travel long distances within each survey period.

Results

Survey Effort

Aerial surveys of Cook Inlet were flown in June or July of each year from 1993 to 2000, generally targeting 40 h per survey season (Table 1). In 1993, surveys were flown in June, July, and September to help establish optimal survey conditions and timing, as well as to refine survey methods. Of primary consideration was to take advantage of the predictable concentrations of belugas in a few river mouths and the ideal weather that is most likely to occur in early summer. Therefore, the June–July period was selected as the preferred time to survey (especially the first half of June), and only results from this period are reported here. Poor visibility interfered with survey effort during only 3% of the total effort during these months, and rarely were flights cancelled on account of weather.

The composite of these aerial surveys provided a thorough coverage for most waters within 3 km of Cook Inlet's shoreline (Fig.1–9). In addition, about 1,000 km of offshore aerial transects were flown each year (Table 1). Although the transect swath was 3 km wide, the effective search area is considered to be 2.0 km (1.4 km on each the left and right, less the 0.8 km blind zone beneath the aircraft). Therefore, the area covered by the coastal plus offshore tracklines each season ranged from 2,534 to 6,500 km^2 ($\bar{x}$ = 4,596 km^2), which means 13–33% ($\bar{x}$ = 23%) of the 19,863 km^2 surface area of Cook Inlet was surveyed annually (Table 1). This calculation does not account for some intersections of offshore transect lines nor for the fact that observers generally searched well beyond 1.4 km; sometimes whales were seen over 6 km away. The distance between the aircraft

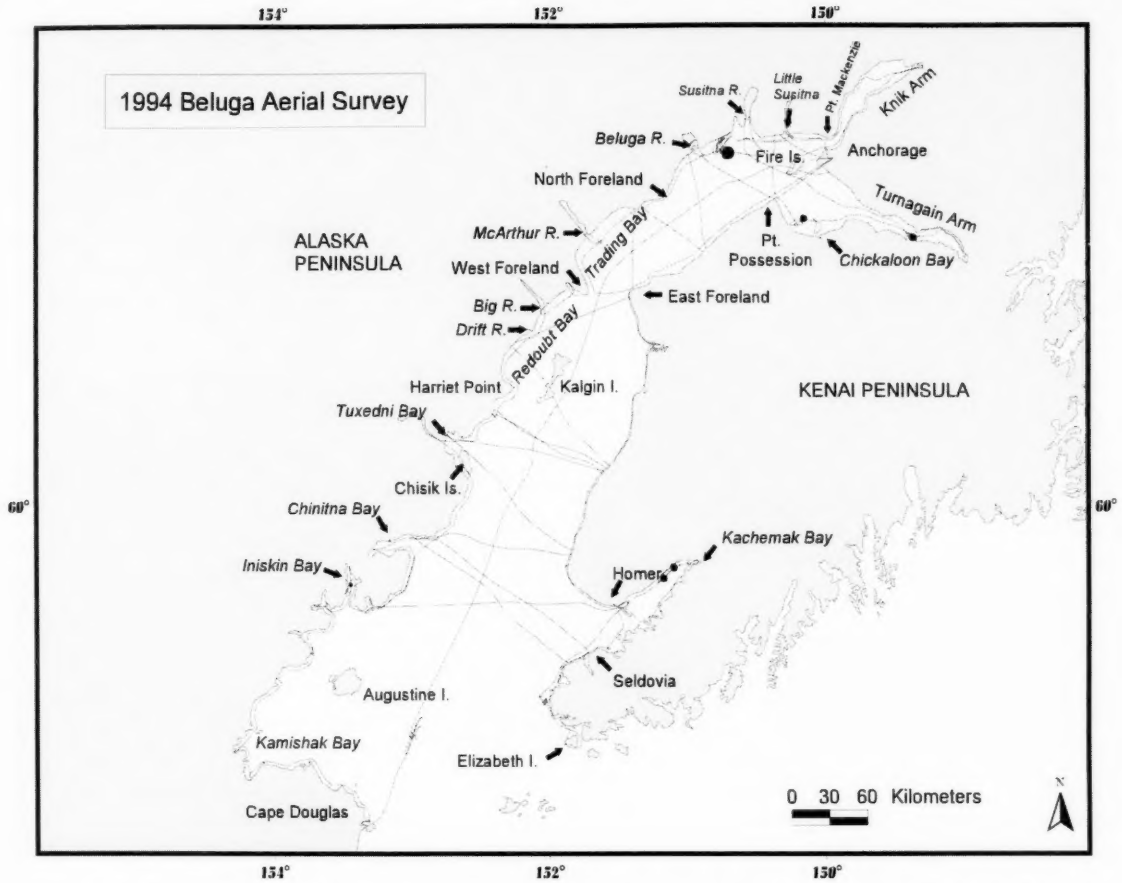

Figure 3.—Beluga groups seen 1–5 June 1994 during coastal and offshore aerial surveys of Cook Inlet. Virtually all of the sightings were near shore or along the edge of mudflats in upper Cook Inlet, and 88% were near the Susitna Rivers. Only 3 small groups were seen in the lower inlet (in Iniskin Bay and Kachemak Bay).

and a beluga group at the moment of the initial sighting ranged from 0.0 to 6.7 km, with a mean of 1.6 km (n = 90; SD = 1.2). Half (49%) of the initial sightings occurred beyond 1.4 km, considered the perimeter of the standard viewing area; therefore, the probability of making a sighting within 1.4 km was high. The correction factor for missed whale groups was only 1.015 (CV = 0.03; Hobbs et al., 2000a) based on results from the paired, independent searches. Although rivers were searched up to 20 km from the inlet, no whale groups were found beyond 4 km from river mouths. Therefore, these annual surveys covered virtually all of the coastal areas in which belugas might occur.

Whale Counts

Aerial counts of belugas in Cook Inlet in June–July during 1993–2000 ranged from 184 to 324 (Table 1). These counts are not corrected for missed whales. Estimations of numbers of whales missed, abundance calculations, and analysis of trends in abundance are presented in Hobbs et al. (2000a). Counts of belugas made in each area on each survey are shown in Table 2, and sighting locations are shown in Figures 1–9.

Sighting Locations

Most beluga sightings were close to the Cook Inlet shoreline or over shallow mudflats (such as over the Susitna Delta, in Knik Arm, or in Chickaloon Bay). Virtually all groups of more than one whale were sighted from the shore side of the aircraft (i.e. within 1.4 km of shore), although some whale groups were so large that they were visible from both sides of the aircraft.

Belugas were found with some consistency in only 3 of the 11 ad hoc areas listed in Table 2 (Fig.1–9). Virtually every summer, a large concentration

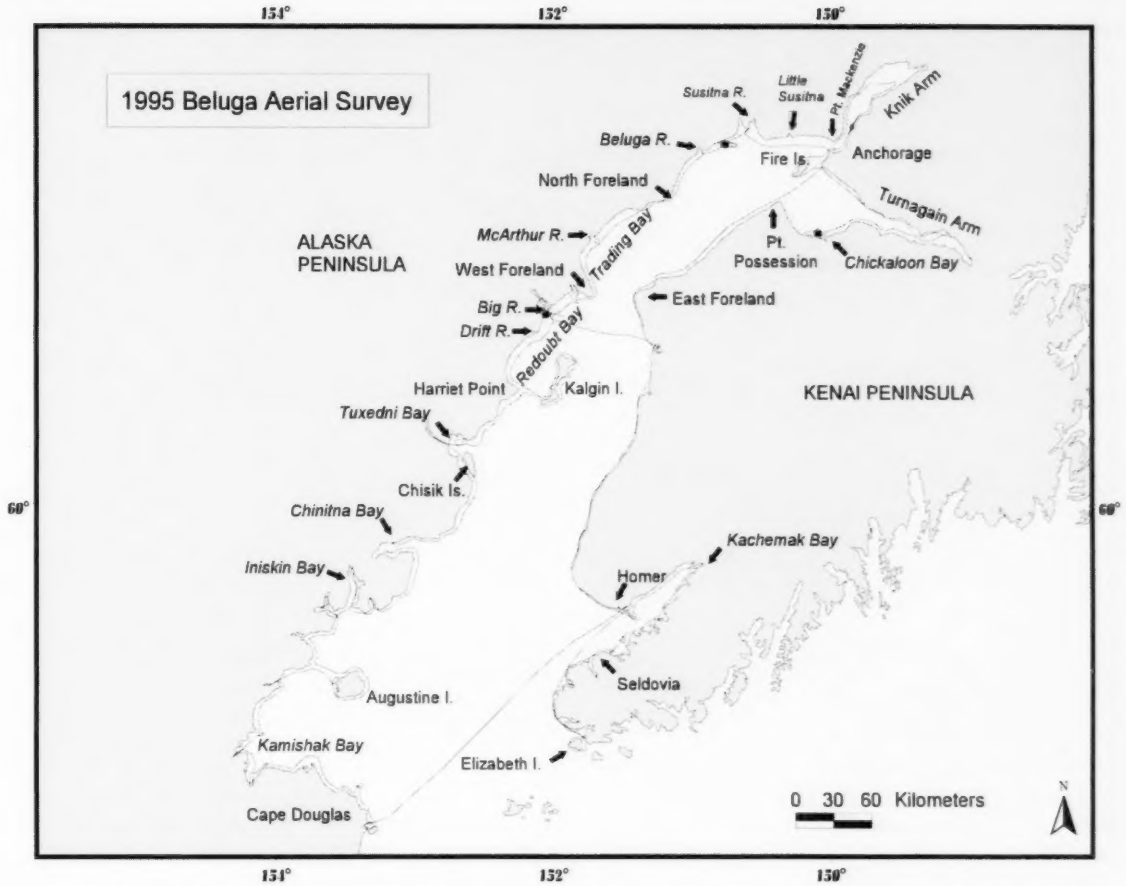

Figure 4.—Beluga groups seen 18–26 July 1995 during coastal and offshore aerial surveys of Cook Inlet. Virtually all of the sightings were near shore or along the edge of mudflats in upper Cook Inlet, and 89% were near the Susitna Rivers. Only 1 small group was seen in the lower inlet (at Big River).

of whales (151–288 by annual aerial counts) was found in the Susitna Delta, or the concentration was split between the Delta and Knik Arm. Whales apparently moved easily between the Susitna Delta and Knik Arm. Crane operators at the Port of Anchorage have also reported seeing several hundred whales at a time in Knik Arm (Smith[6]), and Natives describe how belugas tend to concentrate in Knik Arm later in the summer (Huntington, 2000). Although whales in the Susitna Delta were primarily in dense groups near river mouths, groups in Knik Arm were more dispersed across the tidal channels of the arm.

Besides the groups in the Susitna Delta and Knik Arm, there was only one other group found consistently throughout these surveys. Generally 10–50 whales were counted in Chickaloon Bay, in the area between the Chickaloon River and Point Possession. Elsewhere, such as in Trading Bay (McArthur River), Turnagain Arm, Kachemak Bay, Redoubt Bay (Big River), and other parts of Cook Inlet south of North Foreland and Point Possession, small groups (generally <20 whales) were sometimes seen prior to 1995 but not since then, with the exception of 1 whale in Tuxedni Bay in 1997.

Group Size

Throughout the Cook Inlet surveys, whales were sighted in only 5–11 groups. Most whale groups were large (>20 each) in the Susitna Delta (71%; $n = 17$, using only one survey day per year), but relatively few groups were large elsewhere in upper Cook Inlet (24%; $n = 33$), and none of the 7 groups seen in lower Cook Inlet were large (only 1–14 whales each). All of the whales in the

[6] Smith, B. 1997. NMFS Regional Office, Anchorage, Alaska. Personal commun. via B. Mahoney.

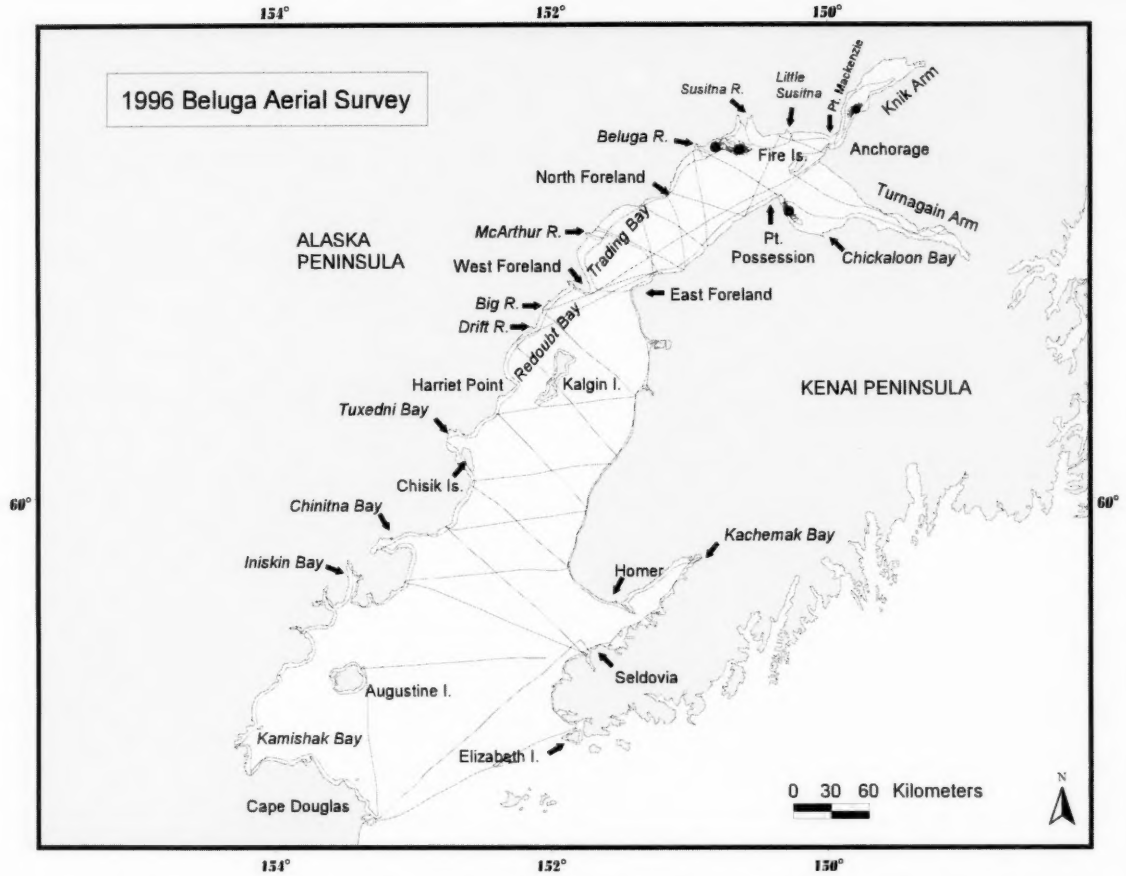

Figure 5.—Beluga groups seen 11–17 June 1996 during coastal and offshore aerial surveys of Cook Inlet. Virtually all of the sightings were near shore or along the edge of mudflats in upper Cook Inlet, and 77% were near the Susitna Rivers. No belugas were seen in the lower inlet.

Susitna Delta were usually concentrated in 1 or 2 large groups (6 of 8 years), but sometimes they split into as many as 4 or 5 groups. In Knik Arm, whales were not seen every year, but when they were, the groups were smaller than in the Susitna Delta and ranged from 1 to 7 subgroups. In Chickaloon Bay, almost all of the whales were in 1 or 2 groups, although sometimes a group was fairly dispersed.

The average density of whale counts within a group in Chickaloon Bay ($\bar{x}$ = 29.4 whales/km^2; SEM = 6.6) was lower (P = 0.003; F = 9.6) than averages in the Susitna Delta ($\bar{x}$ = 68.6; SEM = 7.9) and Knik Arm ($\bar{x}$ = 54.8; SEM =14.9); the Susitna and Knik densities were not significantly different (P = 0.40; F = 0.74). There was no evidence of seasonal changes in the density of whale groups within this sample set (P = 0.40; F = 0.74); mean densities (whales/ km^2 for each group) in the Susitna Delta and Knik Arm were 64 for 8–10 June (n = 10), 66 for 11–16 June (n = 27), and 69 for 18–24 July (n = 6). These date bins were post-stratified to best fit available data.

Lower vs. Upper Cook Inlet

Sightings in lower Cook Inlet (south of lat. 60° 43′N) occurred in low numbers (1–14 whales) from 1993 to 1995, but since then, no whales have been seen there (Table 2), with the exception of a lone whale in Tuxedni Bay in 1997 (Fig. 6) and a dead whale in the middle of the lower inlet in 1998 (Fig. 7). Furthermore, since 1995, only 1 other beluga has been seen south of Pt. Possession or North Foreland (lat. 61° 02′N) other than in Chickaloon Bay. Mean locations of whale groups (based on the most thorough sampling day per season) were weighted as a function of median aerial counts and compared among years (each whale represented by one latitude). This showed a regression northward within this sample period, from 1993 to 2000 (P = 0.054,

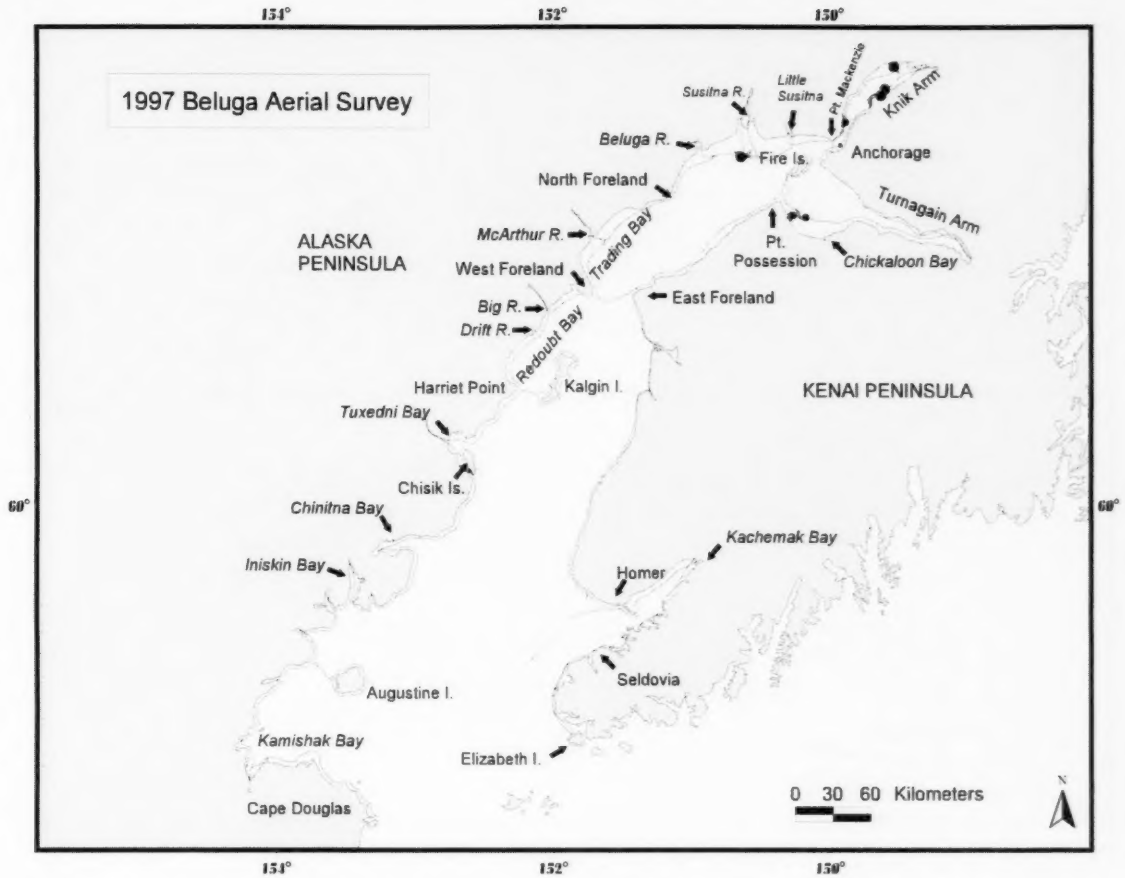

Figure 6.—Beluga groups seen 8–10 June 1997 during coastal aerial surveys of Cook Inlet. Virtually all of the sightings were near shore or along the edge of mudflats in upper Cook Inlet; only 1 whale was seen in the lower inlet (next to Chisik Island). Relatively fewer sightings (28%) were near the Susitna Rivers and more (61%) were in Knik Arm than in previous years.

Theil's nonparametric test for the slope coefficient). Using the same test but with unweighted mean latitudes (each group of whales represented by one latitude) also indicates that there has been a perceptible continuation of the northwardly concentration (P = 0.09), although the trend has not been as pronounced since 1995.

Discussion

Seasonal Distribution Change

Belugas are known to be in upper Cook Inlet between April and November (Huntington, 2000), and because of the predictability of their distribution, most surveys are conducted in summer. June and July are favored for surveying belugas because the whales are more concentrated than at other times of the year and because the lack of sea ice and relatively benign weather maximize the probability of seeing whales. In the past, belugas were more concentrated in the upper inlet in June than in July (Table 3): in the 1970's, the percent of sightings in the upper inlet relative to the lower inlet dropped from 86% in June to 52% in July (averages of two data sets; Calkins[1] and NMFS[7]); and in the 1980's, percentages dropped from 100% in June to 32% in July (NMFS[7]); but in the 1990's, this annual shift in distribution was no longer evident (from 99% to 98% for both June and July).

As summer progresses, whales may disperse away from the uppermost portions of the inlet. For instance, of 157 belugas seen in Cook Inlet during 11 hours of aerial surveys in September 1993, only 73% were in the upper inlet (Withrow et al.[8]). This dispersal

[7] NMFS. 1997. Unpubl. data on file at Platforms of Opportunity Program, NMML, NMFS, NOAA, 7600 Sand Pt. Way, N.E., Seattle, WA 98115.

[8] Withrow, D. E., K. E. W. Shelden, D. J. Rugh, and R. C. Hobbs. 1994. Beluga whale, *Delphinapterus leucas*, distribution and abundance in Cook Inlet, 1993. *In* H. Braham and D. DeMaster

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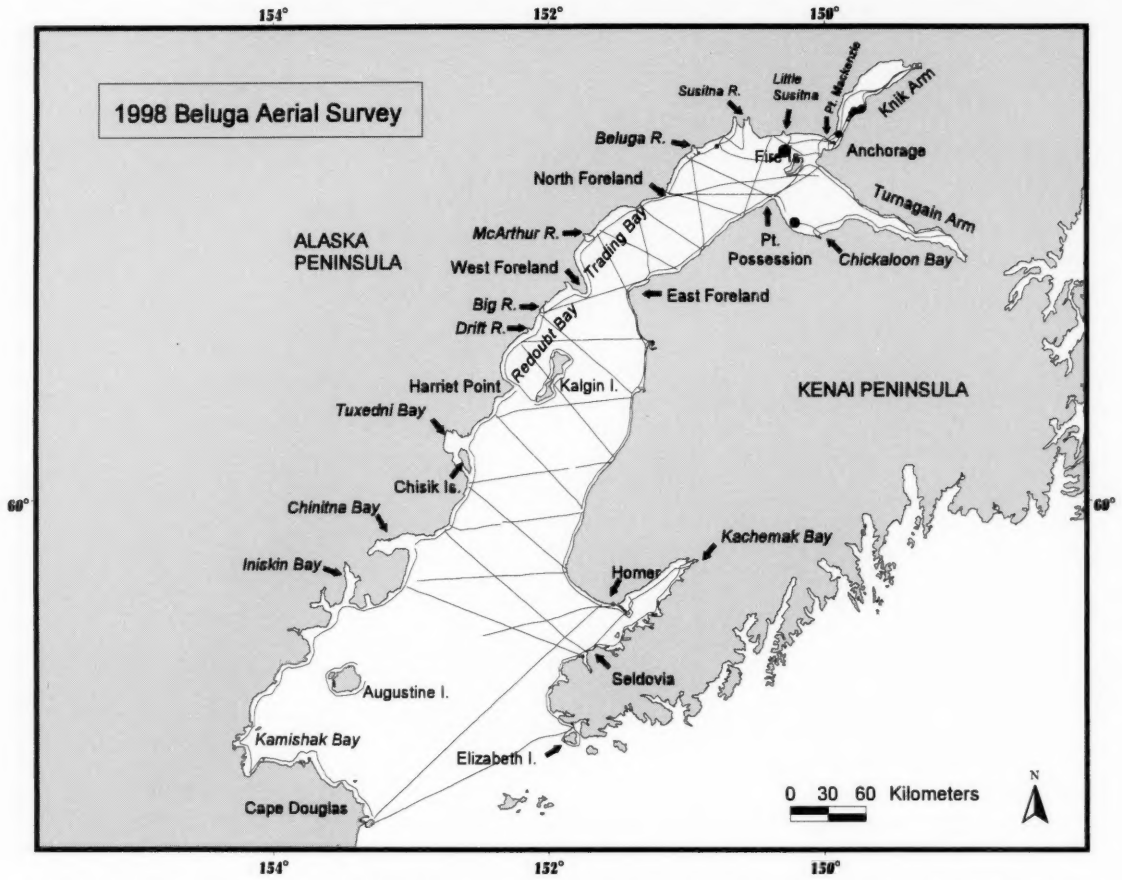

Figure 7.—Beluga groups seen 9–15 June 1998 during coastal aerial surveys of Cook Inlet. Virtually all of the sightings were near shore or along the edge of mudflats in upper Cook Inlet; only 1 (dead) whale was seen in the lower inlet. Most of the whales were near the Little Susitna River and in Knik Arm (78%).

of belugas to other parts of Cook Inlet was also evidenced by sightings in August 1978 of concentrations of 150 belugas in the central part of the inlet (Murray and Fay[4]) and by aerial counts of 160–200 in September 1994, 1995, and 1996 in Tuxedni Bay (Bennett[9]).

A tagged beluga stayed in upper Cook Inlet throughout the period it was monitored, from 31 May to 17 September 1999 (Ferrero et al., 2000). It remained close to the mouth of the Little Susitna River in early June, and then moved into other parts of the upper inlet through the summer, spending time in Knik and Turnagain Arms in September.

There have been very few surveys in Cook Inlet between November and April, and the distribution of belugas has been somewhat enigmatic (Huntington, 2000). There has been a common belief that in winter belugas migrate out of the inlet—or at least out of the upper inlet (Calkins[2]), not because there were sightings elsewhere, but because there were very few sightings in the upper inlet. This was probably just a function of low survey effort in winter and the difficulty of seeing belugas in icy waters. In fact, Native hunters have reported seeing belugas near Tyonek and the Susitna Delta in November (Huntington, 2000). Sightings from drilling platforms in Trading Bay were not uncommon during January (Dahlheim[10]), and reports from a variety of sources (Priewe[11] and several citations in Hansen

[8] *(cont.)* (Editors), Marine Mammal Assessment Program: status of stocks and impacts of incidental take; 1993, p. 128–153. Annu. Rep. submitted to Off. Protected Resour., NMFS, NOAA, 1335 East-West Highway, Silver Spring, MD 20910.

[9] Bennett, A. J. 1996. Physical and biological resource inventory of the Lake Clark National Park-Cook Inlet coastline, 1994–96. Lake Clark Natl. Park and Preserve, Kenai Coastal Off., P.O. Box 2643, Kenai, AK, 99611. Unpubl. manuscr., 137 p.

[10] Dahlheim, R. F., Jr. 16126 Dubuque Road, Snohomish, WA 98290. Personal commun.

[11] Priewe, R. 1997. Priewe Air Service, Anchorage, Alaska. Personal commun. via B. Mahoney.

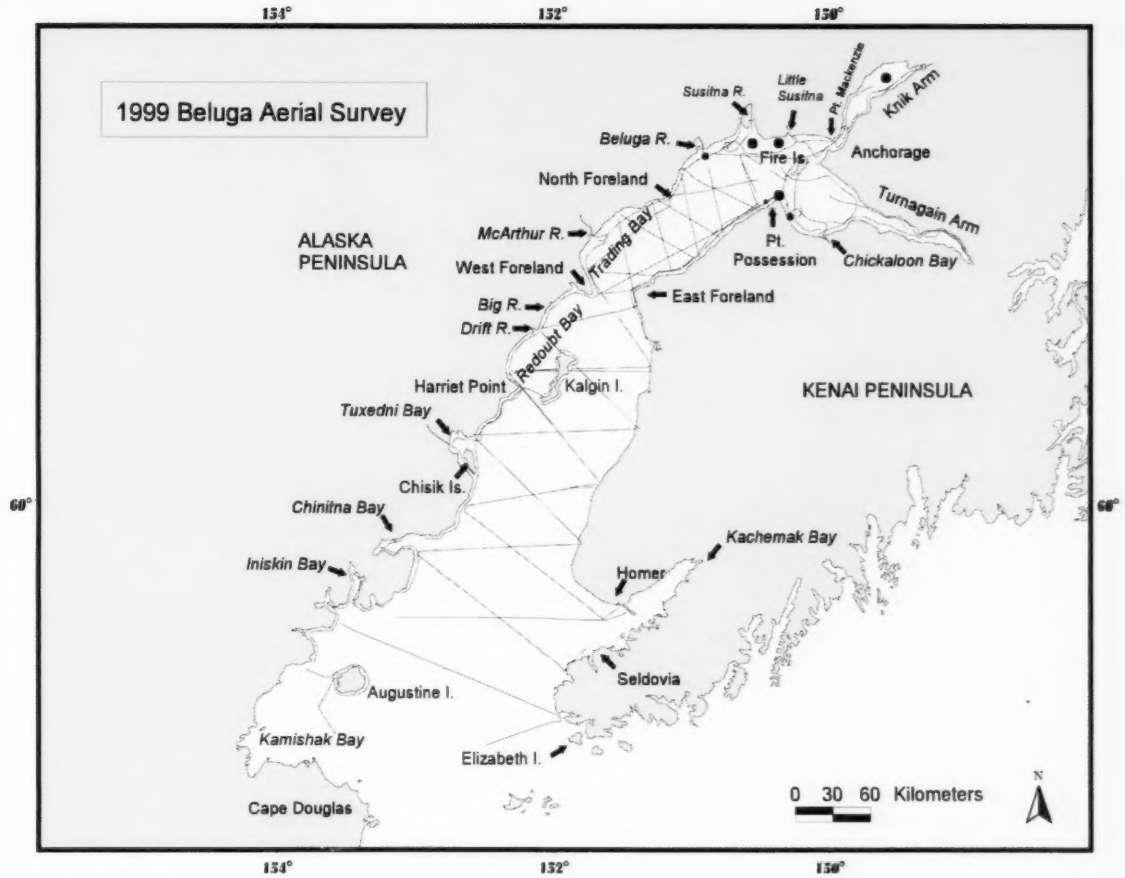

Figure 8.—Beluga groups seen 8–14 June 1999 during coastal aerial surveys of Cook Inlet. Virtually all of the sightings were near shore or along the edge of mudflats in upper Cook Inlet; no belugas were seen in the lower inlet. Most of the whales were between the Susitna Delta and Knik Arm (86%).

and Hubbard, 1999) indicate that belugas have been observed north of the Forelands throughout the winter, even in areas with considerable ice coverage. Calkins[2] concluded that belugas were present in all seasons in the inlet, based on his own sightings. To date there has been only one systematic survey for belugas in Cook Inlet in winter: Hansen and Hubbard (1999) flew 40 h in February and March 1997, counting 150 belugas in 10 sightings, including resightings, mostly in the central parts of the inlet north of Kalgin Island. The theory that the upper inlet is used by belugas even in the winter was substantiated by two whales carrying satellite tags from September 2000 to January 2001 (NMFS[12]). Both whales stayed in upper Cook Inlet throughout this period, almost never going south of the Forelands. These tagged whales, along with the surveys and opportunistic sightings, indicate that waters in central and northern Cook Inlet may be an important winter habitat for these belugas.

Distributional Factors

Lowry (1985) listed four factors that influence seasonal distribution of belugas: 1) access to air (regarding extent of ice cover), 2) water quality and characteristics, 3) access to food, and 4) freedom from excessive predation and other disturbance factors.

Access to Air

Relating these factors to our observations in Cook Inlet, it appears that access to air as a function of sea ice (Factor 1) is not an immediate determinant in beluga distribution in June and July, but it may be in winter. There are variable amounts of sea ice in upper Cook Inlet in winter (Moore et al., 2000). Belugas have been observed in 40–60% ice cover in mid February and in open water in late February and March (Hansen and

[12] NMFS. Maps presented on the web page for Natl. Mar. Mammal Lab. (http://nmml.afsc.noaa.gov/WhatsNew/news.htm).

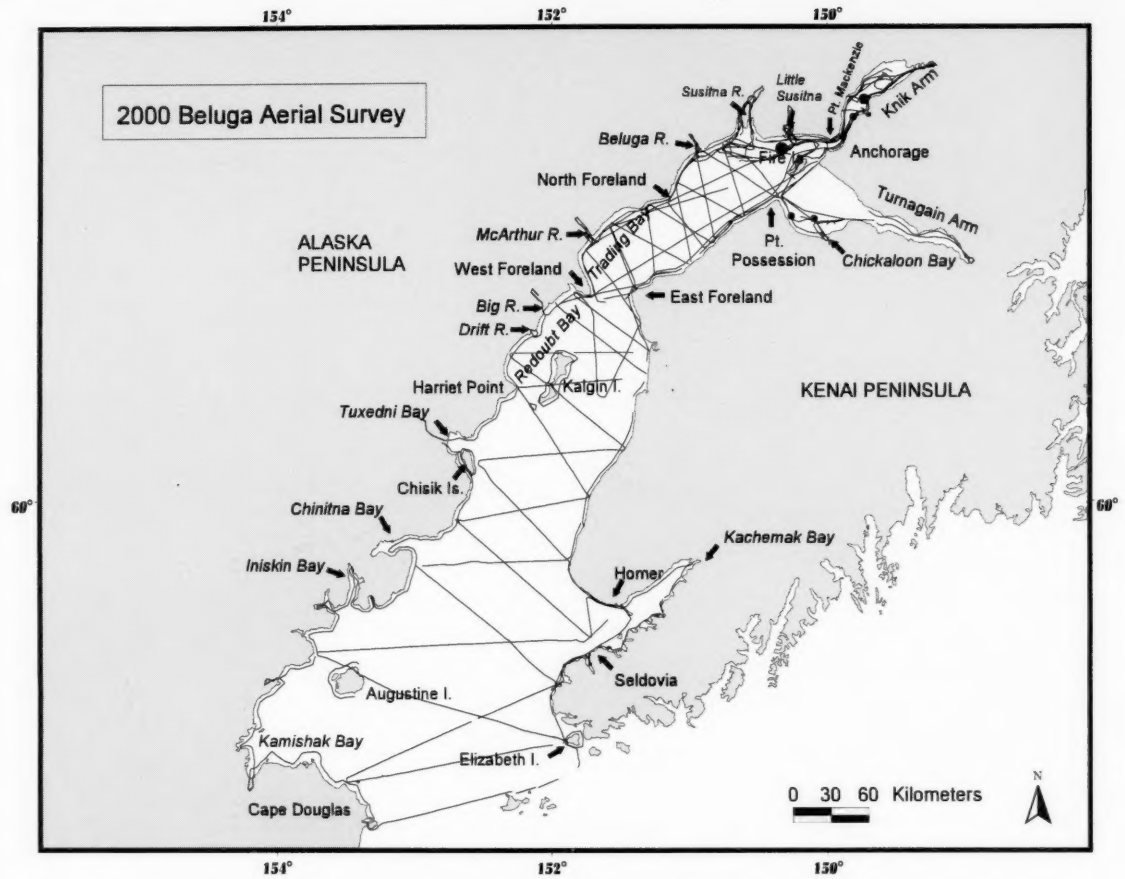

Figure 9.—Beluga groups seen 7–13 June 2000 during coastal aerial surveys of Cook Inlet. Virtually all of the sightings were near shore or along the edge of mudflats in upper Cook Inlet; no belugas were seen in the lower inlet. Most of the whales were between the Susitna Delta and Knik Arm (85%).

Hubbard, 1999). It has been commonly held that belugas retreat from dense ice by moving south to the lower parts of the inlet (Hansen and Hubbard, 1999; Calkins[1]); however, sightings have been made in the upper inlet even with considerable amounts of ice (Priewe[11]), and elsewhere in Alaska, belugas commonly occur in ice-permeated waters (Hazard, 1988).

Water Quality

Water quality (Factor 2) in Cook Inlet is strongly influenced by glacial silt that discolors the water of the upper inlet to the point of appearing as liquid mud. At low tide, this siltation may extend south to the mouth of the lower inlet (Moore et al., 2000). Belugas have obviously developed a tolerance of not being able to see in opaque water with varying salinity, which is characteristic of upper Cook Inlet (Moore et al., 2000). Water quality would probably have only an indirect influence on whale distribution by affecting the distribution of their prey.

Water temperatures range from 8–12°C in early June to 14–16°C in mid July (Moulton[13]). In other areas, such as the Mackenzie Delta of the Beaufort Sea and Kasegaluk Lagoon in the northeastern Chukchi Sea, belugas concentrate in the relatively warm waters of estuaries (as much as 10°C above ocean waters) where prey is not a factor (Hazard, 1988). Because the waters of Cook Inlet are tidally mixed at a high rate (Moore et al., 2000), in June and July belugas do not have distinct thermal advantages in one area over another.

Access to Food

Access to food (Factor 3) may be the overriding element in beluga distribution in June and July (Moore et al., 2000), as described by Natives in Cook Inlet (Huntington, 2000). The consis-

[13] Moulton, L. L. 1994. 1993 northern Cook Inlet smolt studies. ARCO Alaska Sunfish Proj. Rep. prep. for ARCO Alaska, Inc., 700 G St., Anchorage, AK 99510, 100 p.

tency of whale concentrations at river mouths can best be explained as an efficient way for the whales to feed. These coastal concentrations apparently last from April until November (Huntington, 2000) and are very likely associated with the migration of anadromous fish, particularly eulachon, *Thaleichthys pacificus*, and Pacific salmon, *Oncorhynchus* spp. (Moulton, 1997; Huntington, 2000; Moore et al., 2000; Calkins[1,14]; Bennett[9]). However, it is unknown why belugas concentrate at only a few of the many rivers in Cook Inlet and why they are not found at other rivers where presumably fish runs are adequate for their needs.

Predation

Freedom from excessive predation and other disturbances (Factor 4) may be important considerations for beluga distribution in Cook Inlet. The upper inlet experiences extreme tidal fluctuations, and belugas are at risk of becoming stranded (Moore et al., 2000) owing to the inherent risks associated with feeding in opaque waters with rapid changes in depth and strong tidal currents over shallow deltas. However, in spite of these objective hazards, the whales are rarely caught in a stranding by accident (Huntington, 2000), but strandings have occurred when killer whales, *Orcinus orca*, were in the area (Huntington, 2000; Moore et al., 2000). Perhaps the shallow waters of upper Cook Inlet provide some degree of protection, even though strandings may result. Although killer whales may be a primary cause for most baleen whale migrations (Corkeron and Connor, 1999), it is unknown how much their predation affects beluga distribution in Cook Inlet.

Another hazard is beluga philopatry to areas accessible to hunters (Caron and Smith, 1990). Perhaps, because of their need to rebuild fat reserves in the spring, belugas have such a strong drive to feed on fish runs that they remain in feeding areas, even when pursued by hunters (Nuglene[15]). By late June or July, the whales become increasingly more wary of approaches by boats; we have observed entire groups leaving an area when a boat was near. This change in sensitivity may be correlated to changes in fish runs in that the belugas may be relatively tolerant of boats when fish are abundant and easy to catch.

Aircraft, on the other hand, pose no apparent threat to the whales, as they have habituated to the aerial traffic generated by several major airports around upper Cook Inlet. Caron and Smith (1990) observed no changes in swim directions of belugas in eastern Hudson Bay, Canada, when aircraft passed >300 m overhead. Our surveys were consistently flown near 244 m, but belugas did not exhibit overt avoidance behaviors. Sometimes whale groups split or merged, but it did not seem to be in response to the aircraft. In fact, often whales were swimming in the same direction and speed throughout the aerial circling procedure, without any apparent change in activity.

Table 1.—Summary of aerial survey effort conducted by NMFS in Cook Inlet, Alaska, searching for belugas. Counts are the highest of the daily medians of multiple-observer counts for each site for each season.

Dates	Flight hours	Total coverage[1]	Offshore transects	Total groups[2]	Total counts	Upper Cook Inlet counts[3]
1993 June 2–5	13.4	2,534 km^2 (13%)	410 km	11	304	303 (99.7%)
1993 July 25–29	14.8	2,660 km^2 (13%)	557 km	6	271	271 (100.0%)
1994 June 1–5	25.2	4,872 km^2 (25%)	1,129 km	9	281	271 (96.4%)
1995 July 18–26	40.0	4,139 km^2 (21%)	493 km	7	324	310 (95.7%)
1996 June 11–17	39.7	5,852 km^2 (29%)	1,538 km	8	307	307 (100.0%)
1997 June 8–10	22.6	2,894 km^2 (15%)	86 km	10	264	263 (99.6%)
1998 June 9–15	39.4	5,709 km^2 (29%)	1,320 km	9	193	193 (100.0%)
1999 June 8–14	41.5	6,200 km^2 (31%)	1,790 km	7	217	217 (100.0%)
2000 June 7–13	43.0	6,500 km^2 (33%)	1,841 km	7	184	184 (100.0%)
Averages	31.1	4,596 km^2 (23%)	1,018 km	8	261	258 (98.9%)

[1] Coverage is calculated from flight distance times a 2 km-wide swath, a modest estimate of the effective viewing area. Most coastal areas were surveyed several times each season, but coverage calculations included each area only once. Offshore transects are included in this calculation. Percent coverage is based on 19,863 km^2 total surface area of Cook Inlet.

[2] Excluding recounts of groups.

[3] Parenthetic numbers indicate the percentages in the upper inlet relative to the lower inlet.

Reproductive Condition

Reproductive condition is an additional factor potentially affecting whale distribution. Although small, dark beluga calves and young were observed during the summer surveys, no apparent pattern indicated calving areas. Natives describe a calving period from April through August (Huntington, 2000), and they indicate that calving areas include most of the areas where belugas concentrate. The southernmost beluga sighting in Cook Inlet in our study was of an adult with a calf or yearling in a fiord (Iniskin Bay) far from other groups. Elsewhere, calves were seen in very large groups of adults and juveniles in upper Cook Inlet. Calves are so much more difficult to see than adults (Hobbs et al., 2000b) that sighting records from the aerial surveys are not considered an optimal mechanism for assessing the proportion of calves to adults.

Sightings in Lower Cook Inlet

The concentrations of belugas observed in upper Cook Inlet during June and July 1993–2000 were similar to reports from previous studies (e.g. June sightings in Calkins[1]), but our low sighting rates in lower Cook Inlet were in

[14] Calkins, D. G. 1989. Status of belukha whales in Cook Inlet. *In* L. E. Jarvela and L. K. Thorsteinson (Editors), Proceeding of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information update meeting, 7–8 Feb. 1989, Anchorage, Alaska, p. 109–112. U.S. Dep. Inter., Minerals Manage. Serv., OCS Study, MMS 89-0041.

[15] Nuglene, A. 1997. Subsistence hunter. Personal commun. via B. Mahoney.

Table 2.—Counts of belugas made during NMFS' aerial surveys of Cook Inlet in June/July 1993 to 2000. When multiple surveys were done in an area, median counts from each survey day (typically based on 4 counts from each of 2–4 observers) are shown on separate lines. Counts here do not indicate the number of groups seen in the respective area on each day. Dashes indicate no survey, and zeros indicate that the area was surveyed but no whales were seen. Summary figures use the highest medians from each area (or combination of medians between neighboring areas) for the respective season (in bold).

Survey area (in clockwise order)	June 1993	July 1993	June 1994	July 1995	June 1996	June 1997	June 1998	June 1999	June 2000
Upper Cook Inlet									
Trading Bay	1	**30**	0	0	0	0	0	0	0
(McArthur R.)	**3**	0	0	**4**	0	0	0	0	
	0	0	0	0		0	0	0	
		29		0[1]					
				2					
Susitna Delta	**163**	59	197	**287**	124	72	59	89	100
(N Foreland to	122	150	119	140	159	51	57	75	104
Pt. Mackenzie)	166[2]	**221**	244	178	138	**73**	69	**160**	**114**
	100	184	**248**	190	157		**109**	109	67
		201		199	**237**				
Fire Island	0	0	0	0	0	0	11[2]	0	0
	3[2]	0		0	0		0		0
	0	0		0	0		0		0
				0					
Knik Arm	**80**	0	0	0[3]	7	139	83[2]	43[2]	24
	0	0	0	0	17	**161**	71[2]	**27**	**42**
		0		**1**	20		**42**	14	65[2]
					29				
Turnagain Arm	0	0	**5**	0[1]	0	0[1]	0	0	0
(east of Chickaloon Bay)	**8**	0	0	0[1]	0	0[1]	0		
				0[1]	0		0		
Chickaloon Bay/	**49**	0	15	17	17	**29**	23	17	6
Pt. Possession	29	**20**	11	16	**41**	26	**42**	**29**	**28**
	0		**17**	10	21		41		
				18					
Pt. Possession to	0	0	0	0	0	0	0	0	0
East Foreland	6[2]	0	0	0	0	0	0	0	0
	0	0	**1**	0	0	0	0	**1**	0
	0	0		0				0	
Lower Cook Inlet									
East Foreland to Homer	0	0	0	0[1,3]	0	0	0	0	0
Kachemak Bay	0[4]	—	**8**	0[1]	0	0	0	0	0
West side lower Cook Inlet	—	—	**2**	0	0	**1**[1]	0	0	0
Redoubt Bay (Big R.)	**1**	0	0	**14**	0	0	0	0	0
				2					
Sum of highest medians	**304**	**271**	**281**	**324**	**307**	**264**	**193**	**217**	**184**

[1] Visibility was compromised due to weather conditions.
[2] Not used in the summaries because these groups may have already been included in other areas on other days, or a higher count was obtained by combining two neighboring areas.
[3] Possible sighting of a beluga.
[4] Incomplete survey of this area.

Table 3.—A comparison of June and July sightings of belugas in upper Cook Inlet relative to the lower inlet. Counts are cumulative across several survey seasons in the respective categories.

	June counts			July counts		
		Upper Cook Inlet			Upper Cook Inlet	
Dates	Total (sample size)	counts	percentages	Total (sample size)	counts	percentages
1970's[1]	419	368	88%	789	438	56%
1970's[2]	64	48	75%	578	276	48%
1980's[2]	238	238	100%	257	82	32%
1990's[3]	1,750	1,738	99%	595	581	98%

[1] ADFG data (Calkins, text footnote 1), 1974–79.
[2] NMML unpublished data in Platforms of Opportunity database (NMFS, text footnote 7), 1980–88.
[3] Data from the current study (sum of annual medians), 1993–2000.

contrast with other reports (Calkins[1]; NMFS[7]; Fig. 10). In fact, since 1995, we have seen only one live and one dead beluga south of the Forelands in the lower inlet. This drop in sighting rates was despite our emphasis on completing thorough, annual circuits of the entire coastline, searching specifically for belugas. The paucity of beluga sightings here was not simply an issue of poor visibility, because other marine mammals, such as sea otters, *Enhydra lutris*; harbor seals, *Phoca vitulina*; Steller sea lions, *Eumetopias jubatus*; and harbor porpoise, *Phocoena phocoena*, were seen in abundance in the lower inlet.

During vessel operations conducted in offshore waters of Cook Inlet in June and July 1974 to 1979 (Fig. 10; NMFS[7]), 50% of the 642 recorded belugas were in the lower inlet. In the 1980's, 35% of 495 recorded belugas were in the lower inlet, compared with only 1% of the 2,345 sightings in the 1990's (Tables 2, 3). Sighting effort was not well documented in previous studies, so if there had been more surveys in the upper inlet than the lower inlet

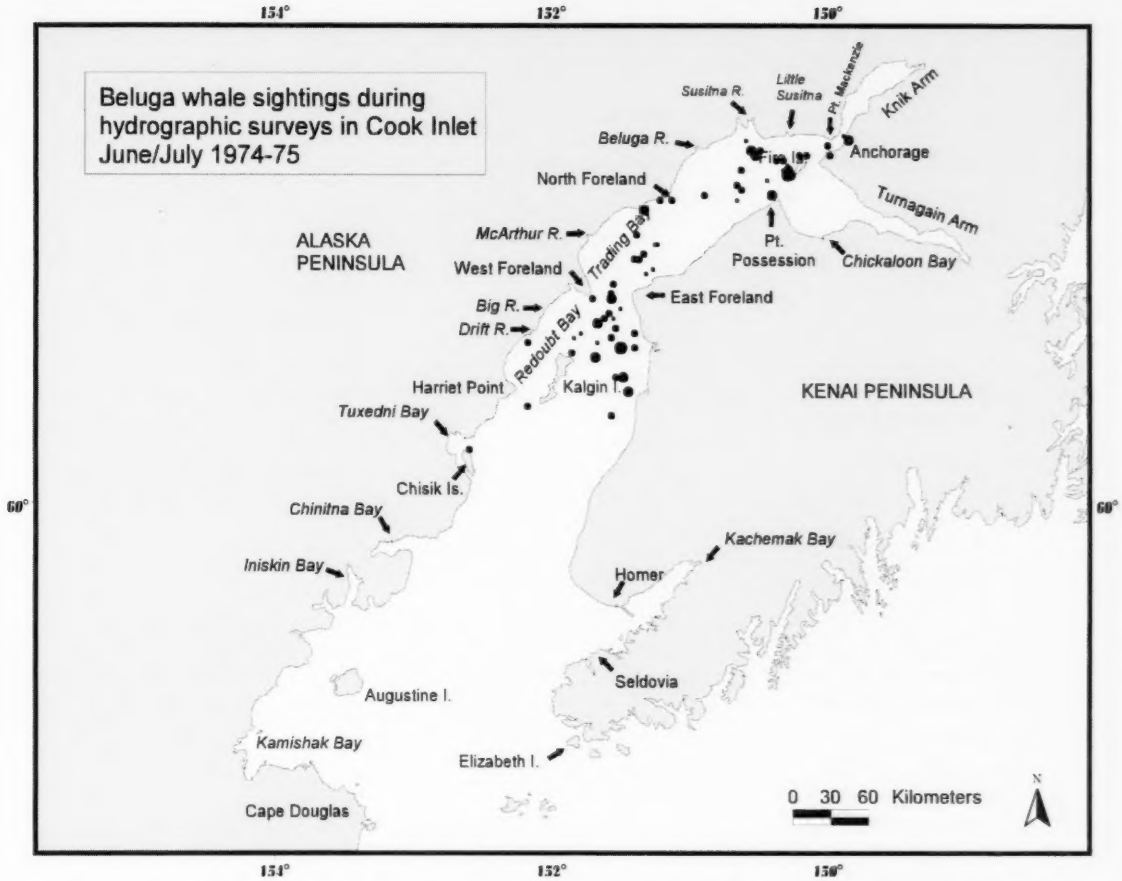

Figure 10.—Beluga sightings during hydrographic surveys in Cook Inlet during June and July 1974–75 (NMFS, text footnote 7). Note that most of the sightings were well offshore, and many sightings occurred in lower Cook Inlet, in contrast to sightings made in the 1990's.

(which is likely because almost all aerial surveys in this area were based out of Anchorage, and virtually all of the surveys targeted areas in the upper inlet where belugas were known to occur), the decline in sightings has been underestimated.

Calkins[2] (p. 40) indicated that belugas were "seen throughout the year in the central and lower inlet, with heaviest use occurring in the central area." Whales are known to concentrate in Tuxedni Bay, based on 11 years of observations by seasonal coastal rangers working for the National Park Service (Bennett[16]). Bennett[16] observed small numbers (up to 38) daily in Tuxedni Bay in June and July 1992, but no whales were seen during his surveys from 1 May to late-August 1994 to 1996 (Bennett[9]). This is a further indication that beluga sightings in the lower inlet in summer have become rare. Others report seeing hundreds of belugas continuously throughout Cook Inlet in the 1970's and 1980's, including areas where few are now found (Foster[17]).

Native hunters reported seeing large groups of belugas in the Kenai River in the 1930's, but the numbers have decreased over the decades, and great numbers occurred in Trading Bay until 10–15 years ago (Huntington, 2000). Belugas were seen regularly in Kachemak Bay until about 1996, according to Jack Montgomery, a local tour guide who has logged about 14,000 km/yr over the past 18 years in that area (Adamson[18]). Intense surveys for marine birds and mammals conducted during 1995–99 in late July and early August did not find any belugas in lower Cook Inlet (Speckman and Piatt, 2000).

[16] Bennett, A. 1993. Wildlife Biologist, Lake Clark Natl. Park and Preserve. Letter to D. Rugh, 14 Dec. 1993.

[17] Foster, S. 1997. Pilot. Personal commun. via B. Mahoney.

[18] Adamson, C. 1998. Where are Cook Inlet belugas? Peninsula Clarion (Soldotna Alaska), 11 Dec. 1998, No. 477:2–3.

Because there was poor or no documentation of effort in previous surveys of Cook Inlet, we used a simple, straightforward approach of comparing proportions of sightings north and south of the Forelands in the middle of the inlet. From casual observations, opportunistic records, and dedicated surveys, it was very apparent that many belugas were seen in the lower inlet in the past where currently almost none are found despite increased search intensity. The differences between reports from the 1970's and 1980's relative to the 1990's, as well as our interannual data through the 1990's, indicate that the distribution of belugas has declined significantly.

Sightings in Offshore Areas

Changes may have occurred in the offshore waters of the upper inlet as well. Some of Calkins'[1] June sightings and most of his July sightings from 1974 to 1979 were well offshore. Also, NOAA data from June and July 1974–75 (Fig. 10) (NMFS[7]) show all but a few of the sightings were offshore. In part this is because the latter data were collected from vessel operations, but whales were also observed along the shore during these surveys (Segur[19]). In contrast, our surveys found almost no live belugas in the center of the inlet in spite of excellent viewing conditions and extensive offshore search efforts. Virtually all of our sightings were shoreward of the 10 fathom (18 m depth) line, whereas the preponderance of the reported sightings in the 1970's (Calkins[1]; NMFS[7]) were beyond this depth.

Sightings Beyond Cook Inlet

There have been some sightings of belugas in the Gulf of Alaska outside of Cook Inlet (Laidre et al., 2000); however, considering the amount of effort expended by aerial surveys and extensive vessel operations in the Gulf of Alaska, it is remarkable how few beluga sightings have been recorded. The lack of sightings along the southern side of the Alaska Peninsula indicate that the Cook Inlet stock is not widely dispersed and is isolated from stocks in the Bering Sea. This hypothesis is supported by mitochondrial DNA analyses which show distinct differences between belugas in Cook Inlet relative to other stocks around Alaska (O'Corry-Crowe et al., 1997). Native hunters have also remarked on how distinct the belugas in Cook Inlet are (Huntington, 2000).

Previous Beluga Counts

The number of whales counted during our aerial surveys (184–324) from 1993 to 2000 is roughly 60–80% of Klinkhart's[3] estimates of 300–400 in 1963 and 1964. Similar numbers (about 400) were seen in 1976–78 (Calkins[2]), with the highest count (479) made on 21 August 1979 (Calkins[14]). Murray and Fay[4] counted only 150 on three consecutive days in the central inlet, but these counts did not include the upper inlet. Counts ranged up to 335 in the upper inlet in June and July 1982 and up to 176 in June and July 1983 (Calkins[1]). During a 40-h survey specifically searching for belugas throughout upper Cook Inlet in June 1991 (NMFS[20]), the highest one-day count was 242 whales. Counts of 200 in June 1991 and 255 in June 1992 were made during aerial surveys of upper Cook Inlet while survey teams were en route to or returning from other projects (NMFS[21]). However, prior to our surveys starting in 1993, most counts were not based on systematic surveys for belugas throughout the entire inlet (Calkins[1]). Current counts have resulted from more intensive and focused surveys than were previously conducted. Analysis of trends in recent abundance estimates (1994–2000) with corrections for missed whales are presented in Hobbs et al. (2000a). Declines evident in these abundance estimates are probably reflected in the declines in distribution reported here. There is no evidence that the belugas of Cook Inlet have dispersed to other areas (Laidre et al., 2000) in response to the persistent harvest by Native hunters (Mahoney and Shelden, 2000), so it is evident that this stock was in decline during this period.

Acknowledgments

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[19] Segur, G. V. 1975. Marine Mammal Officer, NOAA Ship *McArthur*. Memo. to Chief, Fish. Br., PMC Operations Div., Seattle, Wash., 27 Aug. 1975.

[20] NMFS. 1992. Status report on Cook Inlet belugas (*Delphinapterus leucas*). Rep. prep. by Alaska Reg., Natl. Mar. Fish. Serv., 222 W. 7th Ave., Anchorage, AK 99513-7577, 22 p.

[21] NMFS. 1997. Unpubl. data on file at NMML, NMFS Alaska Fish. Sci. Cent., NOAA, 7600 Sand Point Way N.E., Seattle, WA 98115.

Whale Commission and NMFS Alaska Regional Office (AKR) provided partial support for some of the CIMMC observers. Kristin Laidre (NMML) provided data and sighting maps from NOAA's Platforms of Opportunity Program and produced all of the maps used in this publication. Flights were conducted under Scientific Research Permits No. 791 (P771#63) and No. 782-1360. Document reviews were provided by Rod Hobbs (NMML), Brad Smith (AKR), Marcia Muto (NMML), David Withrow (NMML), Gary Duker (AFSC Publications Unit), and three anonymous reviewers.

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Historic and Current Use of Lower Cook Inlet, Alaska, by Belugas, *Delphinapterus leucas*

SUZANN G. SPECKMAN and JOHN F. PIATT

Introduction

The number of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska is small—about 350 individuals in 1998—and the population is declining (Hobbs et al., 2000). The Cook Inlet stock of belugas is currently listed as "depleted" under the Marine Mammal Protection Act (Fed. Regist. 65:34590–4597, 31 May 2000), but it is currently not listed as endangered under the Endangered Species Act (Fed. Regist. 65:38778–38790, 22 June 2000). Belugas have been harvested in Cook Inlet by Native hunters since prehistoric times and by commercial and sport hunters intermittently since the early 1900's (Shelden and Mahoney, 2000). The recent decline of the beluga population in Cook Inlet has been attributed largely to harvesting.

Although hunting has been a point of concern and an obvious source of mortality for this population, belugas are likely affected by other factors that are currently under assessment, such as changes in habitat quality (Moore et al., 2000) and declining prey availability or abundance (Anderson and Piatt, 1999; Moore et al., 2000; Speckman and Piatt[1]). Increased vessel traffic may also disturb belugas (Erbe and Farmer, 2000; Moore et al., 2000). Changes in environmental conditions may exacerbate losses from hunting and contribute to the ongoing population decline, or inhibit recovery.

Most surveys focused on belugas in Cook Inlet have taken place in June, when the whales are concentrated near river mouths and are therefore easier to count (Hobbs et al., 2000; Rugh et al., 2000). Some survey work was conducted in mid February and mid March 1997 (Hanson and Hubbard[2]), but little is known about the distribution and range of Cook Inlet belugas at other times of the year.

We conducted dedicated at-sea surveys for marine birds and mammals in lower Cook Inlet in late July and August of 1995–99. Our main objective was to document the distribution and abundance of marine predators in relation to forage fish and to examine changes in distribution and abundance among years. In addition, we consulted long-term residents of Cook Inlet to obtain anecdotal information on the historical abundance and distribution of belugas within the study area.

Methods

We surveyed for marine birds and mammals in lower Cook Inlet south of Kalgin Island in late July and August from 1995 to 1999 (Table 1). Surveys followed transects established in both "nearshore" and "offshore" habitats. Nearshore transects followed the contours of mainland or island shorelines, where waters were generally deeper than 10 m. Offshore transects cut across open water from one shore to another, over depths ranging from 10 m to >200 m.

In 1995, surveys were concentrated around the mouths of Tuxedni Bay, Kachemak Bay, and northeast of the Barren Islands (Fig. 1), where seabirds are concentrated. In 1996, coverage was more extensive, and in addition to areas surveyed in 1995, included areas in western lower Cook Inlet and south of the Barren Islands that were not surveyed in subsequent years (Fig. 2). In 1997–99, surveys were similar to and slightly more extensive than those in 1995 (Fig. 3). Transects surveyed from 1997–99 were identical in all 3 years of the study with the exception of the

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ABSTRACT—Dedicated at-sea surveys for marine birds and mammals conducted in lower Cook Inlet in late July and early August from 1995–99 failed to locate any belugas, Delphinapterus leucas. *Surveys covered a total of 6,249 linear km and were conducted in both nearshore and offshore habitats. Sightings included 791 individual marine mammals of 10 species. Both historical data and local knowledge indicate that belugas were regularly seen in summer in nearshore and offshore areas of lower Cook Inlet up until the early 1990's. Diminished presence of belugas in lower Cook Inlet may be a direct function of reduced numbers but may also indicate changes in habitat quality that may inhibit recovery.*

[1] Speckman, S. G., and J. F. Piatt. 2000. Biological Resources Division, U. S. Geological Survey, 1011 E. Tudor Road, Anchorage, AK 99503. Unpubl. data.

[2] Hanson, D. J., and J. D. Hubbard. 1999. Distribution of Cook Inlet beluga whales (*Delphinapterus leucas*) in winter. Final Report. OCS Study MMS 99-0024. U.S. Department of the Interior, Minerals Management Service, Alaska Outer Continental Shelf Region, Anchorage, AK.

furthest north nearshore transect, which was not surveyed in 1997.

In 1995 and 1997–99, surveys were conducted from the R/V *Pandalus*, a 22 m stern trawler operated by the Alaska Department of Fish and Game. Surveys in 1996 were conducted from the R/V *Tiglax*, a 36 m vessel operated by the Alaska Maritime National Wildlife Refuge, U.S. Fish and Wildlife Service. In all years, surveys in some shallow nearshore areas were conducted from the R/V *David Grey*, an 11 m cabin cruiser operated by the Biological Resources Division of the U.S. Geological Survey. Ground speed for all vessels was approximately 11–15 km/h (6–8 kn).

Surveys were conducted according to protocols established by the U.S. Fish and Wildlife Service for marine birds (Gould and Forsell[3]). Observers actively scanned by naked eye ahead of and alongside the survey vessel. Special effort was made to locate and identify cetaceans beyond transect boundaries. Species identifications were confirmed using 7- or 10-power binoculars. All surveys took place during weather conditions suitable for sighting small marine birds at 150 m.

Bird and mammal sightings were recorded by entering them directly into a real-time computer data-entry system (DLOG[4]) that plots animal positions continuously using GPS coordinates. At all times, 1 person entered data into the computer, located in the wheelhouse, while observers surveyed from the best vantage points of each vessel (Table 2). Sightings were immediately called to the data entry person over hand-held VHF radios. Transects widths ranged from 200 to 300 m (Table 2).

For all surveys, swimming birds and mammals within transect boundaries were counted, identified to species, and recorded as "on transect." Birds and mammals sighted in front of the survey vessel at a distance of approximately twice the width of the transect were also considered "on transect," to counteract biases introduced when timid species avoided the survey vessel. Mammals were recorded as "off transect" when identified beyond the transect boundary.

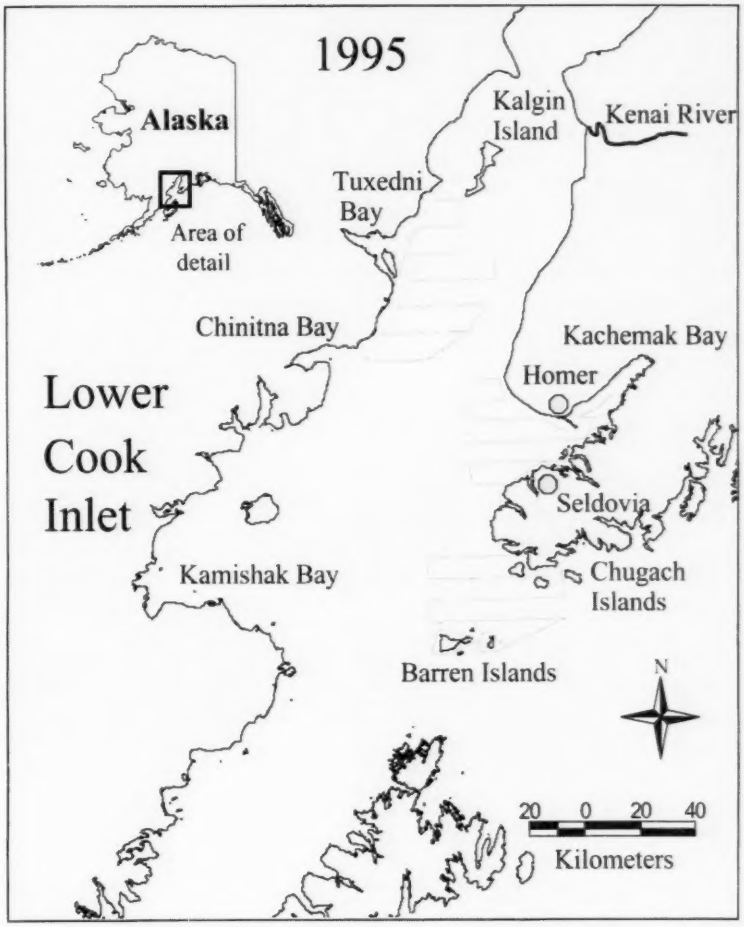

Figure 1.—Transects surveyed in both nearshore and offshore areas in 1995.

Table 1.—Total number of linear and square kilometers surveyed in lower Cook Inlet and harbor porpoise sighting rates during marine bird and mammal surveys, 1995–99.

Survey year	Survey dates	Nearshore		Offshore		Total		Harbor porpoise sighting rate[1]
		km	km²	km	km²	km	km²	#/km
1995	10–23 Aug.	115	15	705	138	820	153	0.00
1996	14–31 July	561	126	1,491	447	2,052	574	0.05
1997	19 July–08 Aug.	459	138	651	195	1,110	333	0.81
1998	21 July–12 Aug.	482	145	649	195	1,130	339	0.62
1999	25 July–16 Aug.	481	144	656	197	1,137	341	1.06

[1] Speckman and Piatt, unpubl. data

Results and Discussion

The number of linear kilometers surveyed each year ranged from 820 to 2,052 (Table 1). Nearshore transects comprised from 14 to 43% of the total kilometers surveyed; the remainder were

[3] Gould, P. J., and D. J. Forsell. 1989. Techniques for shipboard surveys of marine birds. U.S. Department of the Interior, Fish and Wildlife Service, Washington, D.C. Fish and Wildlife Technical Report 25, 22 p.

[4] DLOG, Ecological Consulting Inc., Portland, Oreg. Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

offshore transects. A total of 791 marine mammals of 10 species were sighted; however, no belugas were seen in any year. It seems unlikely that belugas were missed on these surveys, given that they are easily identified and that our sightings included many small marine mammal species such as sea otters, *Enhydra lutris*; harbor seals, *Phoca vitulina*; harbor porpoises, *Phocoena phocoena*; and minke whales, *Balaenoptera acutorostrata*.

Table 2.— Summary of survey vessel parameters and survey effort in lower Cook Inlet during marine bird and mammal surveys, 1995–99.

Survey year	Transect type	Transect width (m)	Vessel	Observer height (m)	Number of observers
1995	Nearshore	200	*Pandalus*	3.4	2–3
	Offshore	200	*Pandalus*	3.4	2–3
1996	Nearshore	200	*David Grey/Pandalus*	0/3.4	2–3
	Offshore	300	*Tiglax*	8.5	4
1997	Nearshore	300	*David Grey/Pandalus*	2.4/3.4	1–2
	Offshore	300	*Pandalus*	3.4	1–2
1998	Nearshore	300	*David Grey/Pandalus*	2.4/3.4	1–2
	Offshore	300	*Pandalus*	3.4	1–2
1999	Nearshore	300	*David Grey/Pandalus*	2.4/3.4	1–2
	Offshore	300	*Pandalus*	3.4	1–2

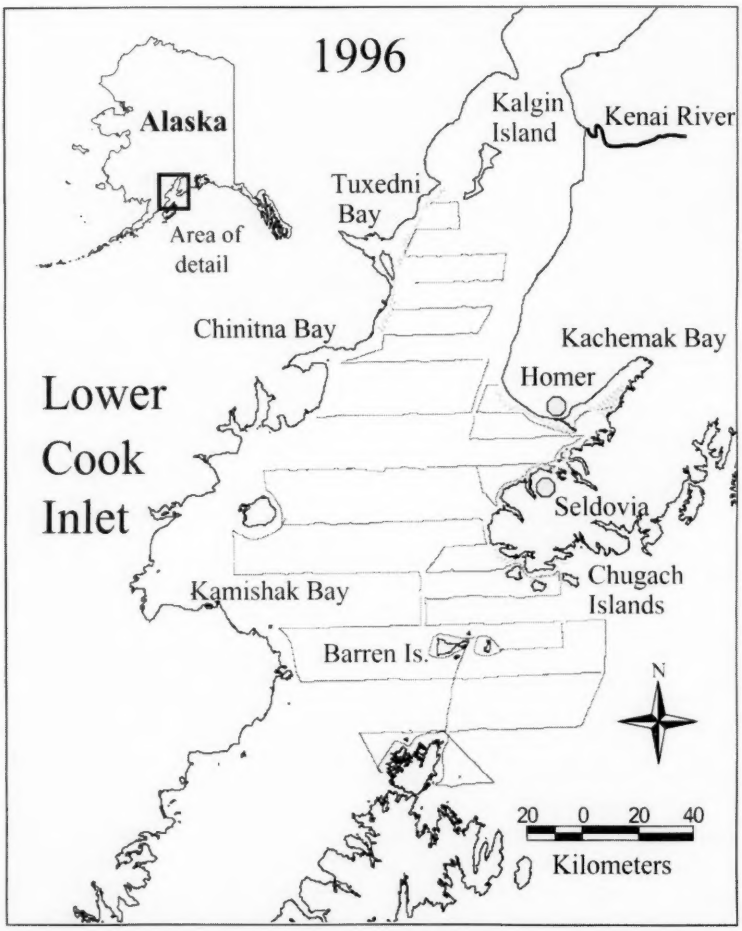

Figure 2.— Transects surveyed in 1996. Survey coverage was most extensive in 1996, and included areas not surveyed in other years.

The lack of beluga sightings during our intense surveys in lower Cook Inlet suggests that there were no large groups in the survey area during late July and August 1995–99. To index our ability to see small cetaceans during our surveys, we calculated annual sighting rates for harbor porpoises (Table 1), which are arguably more difficult to detect than larger, white belugas. Harbor porpoise sighting rates varied annually, probably in large part due to the different areas surveyed. Although belugas were not seen, harbor porpoises were reliably detected, especially in 1997, 1998, and 1999, over a relatively broad survey area in lower Cook Inlet (Fig. 3).

The results of our study are corroborated by those of a study on beluga distribution in Cook Inlet conducted in 1993–99 by Rugh et al. (2000), who concluded that the summer range of belugas in Cook Inlet had diminished over the past 3 decades, becoming progressively more restricted to the northern reaches of Cook Inlet.

Local knowledge and other historical evidence show that, prior to the 1990's, belugas were regularly seen in lower Cook Inlet waters, both nearshore and offshore (Rugh et al., 2000). Sightings were most frequent in spring and fall, and belugas were regular visitors in lower numbers throughout the summer months.

In Kachemak Bay, beluga sightings now are far fewer and group sizes are smaller than 7 or 8 years ago (Matkin[5]). In the past, belugas were regular visitors to the Homer Spit and the head of Kachemak Bay, appearing during spring and fall of some years in groups of 10–20 individuals that remained for a few days at a time. In the fall of 1999, only 4 belugas were seen near the spit (Matkin[5]). The previous reported sight-

[5] Matkin, C. 2000. North Gulf Oceanic Society, P.O. Box 15244, Homer, AK 99603. Personal commun.

ing for Kachemak Bay was 8 individuals in 1994 (Rugh et al., 2000).

A similar pattern has been noticed in Chinitna Bay by 25-year residents (Haeg and Haeg[6]). In the late 1970's and 1980's, groups of 50 or more belugas were common in Chinitna Bay, gathering at the mouths of streams during salmon runs. Smaller groups of 5–20 animals were seen occasionally in June and commonly in July. For the past 10 years, beluga sightings have been far fewer and group sizes have been smaller than in the 70's and 80's. Near Polly Creek, just north of Tuxedni Bay, use of the area by belugas has decreased markedly since 35 years ago (Swiss[7]). Belugas were seen regularly all summer in groups of 25–300 animals until 5–6 years ago; now, sightings are rare, and group sizes range from 10 to 75.

Belugas exhibit a variety of responses to vessel traffic, from little discernable response to desertion of an area with frequent boat traffic (reviewed by Richardson, 1995). Increased boat traffic in lower Cook Inlet, especially the use of loud vessels such as air boats in and around Pacific salmon, *Oncorhynchus* spp., spawning rivers and streams, may negatively impact the availability of salmon to belugas if belugas are avoiding such vessels. Residents of Chinitna Bay (Haeg and Haeg[6]) are concerned about the impacts of air boats on belugas, and such concerns should be investigated as part of a management plan for Cook Inlet belugas.

Diminished presence of belugas in lower Cook Inlet may be a result of reduced population size. As the population has declined, belugas may simply be sighted less often. Their range may be contracting as peripheral habitats are abandoned in favor of preferred habitats. Alternatively, diminished presence of belugas may indicate that the importance of various habitats to belugas has changed as prey species have declined, or as belugas have begun to utilize alternate prey species in other areas. Fish species composition in the Gulf of Alaska has changed dramatically over the past 20 years (Piatt and Anderson, 1996; Anderson and Piatt, 1999), and shifts in prey species composition may be accompanied by shifts in prey quality (van Pelt et al., 1997) for predators.

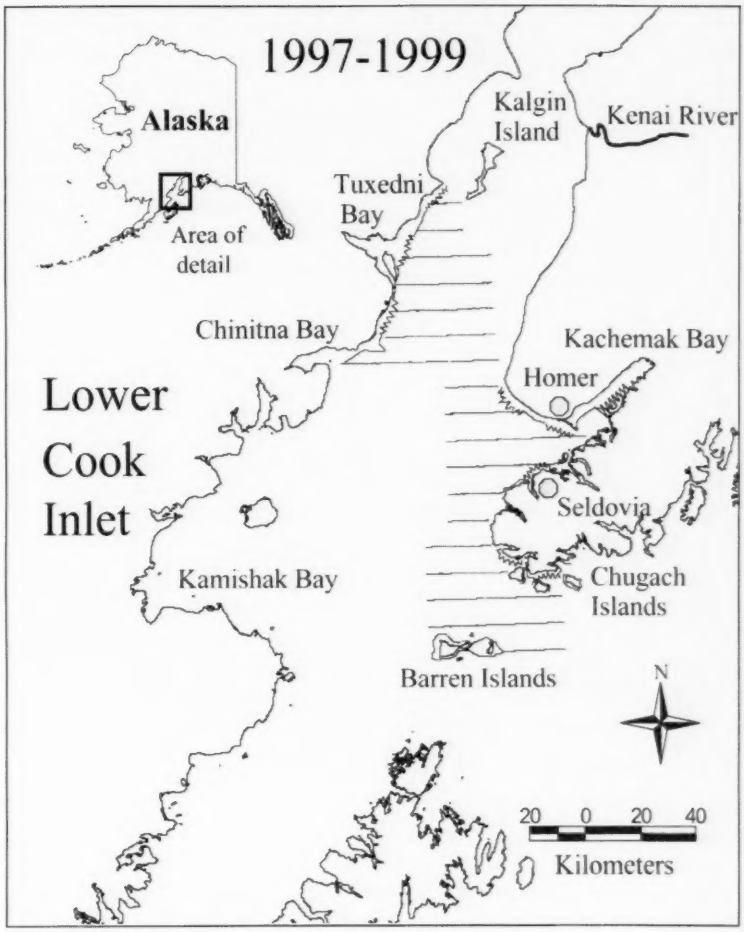

Figure 3.— Transects surveyed from 1997 to 1999.

Moore et al. (2000) discuss habitat associations of belugas and review the status of salmon stocks in Cook Inlet. Another common beluga prey species, eulachon, *Thaleichthys pacificus*, is of uncertain status. Sport fishing harvests of eulachon have declined dramatically during the past 20 years in upper Cook Inlet, possibly indicating declines in eulachon stocks, decreased fishing effort, or both, but lack of data on species-specific fishing effort precludes interpretation of the catch data (Stratton and Cyr[8], Howe et al.[9], Howe[10]). Anecdotal observations indicate declines in numbers

[6] Haeg, M., and B. Haeg. 2000. P.O. Box 338, Soldotna, AK 99669. Year-round residents of Chinitna Bay for 25 years. Personal commun.

[7] Swiss, T. 2000. 8341 Blackberry Street, Anchorage, AK 99502. Resident of Polly Creek for 35 summers. Personal commun.

[8] Stratton, B., and P. Cyr. 1997. Annual management report for the Anchorage area, 1995. Alaska Department of Fish and Game, Fishery Management Report No. 97-01, Anchorage, Alaska, 98 p.

[9] Howe, A. L., R. J. Walker, C. Olnes, G. Heineman, and A. E. Bingham. 1999. Harvest and catch in Alaska sport fisheries during 1998. Alaska Department of Fish and Game, Fishery Data Series No. 99-41, Anchorage, Alaska, 128 p.

[10] Howe, A. L. 2000. Alaska Department of Fish and Game, Division of Sport Fish, 333 Raspberry Road, Anchorage, AK 99518. Personal commun.

in the northern part of the inlet (Kitto[11]). Eulachon populations in lower Cook Inlet have not been assessed, and no information is available to suggest major changes (Fox[12]).

Hunting by Alaska Natives may be a primary cause of the recent decline in the beluga whale population in Cook Inlet, but other factors need to be examined. Shifts in the distribution of belugas in the lower inlet may indicate local or ecosystem-level changes in habitat or prey quality and quantity. Vessel noise and traffic, fishing, and changing sea temperatures and prey communities could all affect beluga habitat choices and exacerbate losses of belugas due to hunting. Such effects may confound or inhibit recovery. A better understanding of these factors, and how they affect belugas both from an individual and a population standpoint, is required before a management plan that affords protection and recovery of belugas in Cook Inlet can be developed.

[11] Kitto, Beth. 2000. U.S. Forest Service, Glacier Ranger District, PO Box 129, Girdwood, AK 99587. Personal commun.

[12] Fox, J. 2000. Alaska Department of Fish and Game, 43961 Kalifornsky Beach Road, Soldotna, AK 99669. Personal commun.

Acknowledgments

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Hobbs, R. C., D. J. Rugh, and D. P. DeMaster. 2000. Abundance of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994–2000. Mar. Fish. Rev. 62(3):37–45.

Mahoney, B. A., and K. E. W. Shelden. 2000. Harvest history of belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska. Mar. Fish. Rev. 62(3):124–133.

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Piatt, J. F., and P. Anderson. 1996. Response of common murres to the *Exxon Valdez* oil spill and long-term changes in the Gulf of Alaska marine ecosystem. *In* S. D. Rice, R. B. Spies, D. A. Wolfe, and B. A Wright (Editors), Proceedings of the *Exxon Valdez* oil spill symposium, p. 720–737. Am. Fish. Soc. Symp. 18, Anchorage, Alaska.

Richardson, W. J., C. R. Greene, Jr., C. I. Malme, and D. H. Thomson. 1995. Marine mammals and noise. Acad. Press, San Diego, Calif.

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van Pelt, T. I., J. F. Piatt, B. K. Lance, and D. D. Roby. 1997. Proximate composition and energy density of some North Pacific forage fishes. Comp. Biochem. Physiol. 118 (A): 1393–1398.

Beluga, *Delphinapterus leucas*, Distribution and Survey Effort in the Gulf of Alaska

KRISTIN L. LAIDRE, KIM E. W. SHELDEN, DAVID J. RUGH, and BARBARA A. MAHONEY

Introduction

Belugas, *Delphinapterus leucas*, are found in five stocks around Alaska: in the Beaufort Sea, eastern Chukchi Sea, eastern Bering Sea, Bristol Bay, and Cook Inlet (Hill and DeMaster, 1998). The geographically and genetically isolated stock in Cook Inlet (O'Corry-Crowe et al., 1997) has been the subject of an annual harvest by Alaska Native hunters. Concerns over the viability of this stock led to a program of regular, systematic aerial surveys each June or July since 1993 (Rugh et al., 2000) along with analysis of the aerial counts (Hobbs et al., 2000a). The resulting abundance estimates indicated that the Cook Inlet beluga population was small and declining (Hobbs et al., 2000b).

With increased attention on the Native harvest in Cook Inlet, there has been a renewed interest in the distribution of belugas elsewhere in the Gulf of Alaska. Huntington (2000) found that winter migration of Cook Inlet belugas into the Gulf of Alaska is a topic of great interest to Alaska Natives. The possibility that belugas are strictly confined to the waters of Cook Inlet is important to the management of the stock. The degree of isolation of Cook Inlet belugas affects the estimation of abundance with concomitant harvest implications.

Accordingly, this paper is a synthesis of available information, showing the number and geographical coverage of surveys in which belugas would have been reported if encountered. The area of coverage extends from Unimak Pass to Dixon Entrance, that is, across southern Alaska and adjacent inside waters (Fig. 1), and includes effort and sighting data from marine mammal research projects in the Gulf of Alaska. Beluga sightings were collated from these dedicated surveys and augmented by opportunistic records from fishing vessels, recreational operations, U.S. Coast Guard patrols, local pilots, and biologists on unrelated studies. The geographical area covered by the larger surveys is schematically demonstrated in the respective Figures 2–7.

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ABSTRACT—Beluga, Delphinapterus leucas, *distribution in the Gulf of Alaska and adjacent inside waters was examined through a review of surveys conducted as far back as 1936. Although beluga sightings have occurred on almost every marine mammal survey in northern Cook Inlet (over 20 surveys reported here), beluga sightings have been rare outside the inlet in the Gulf of Alaska. More than 150,000 km of dedicated survey effort in the Gulf of Alaska resulted in sightings of over 23,000 individual cetaceans, of which only 4 beluga sightings (5 individuals) occurred. In addition, nearly 100,000 individual cetaceans were reported in the Platforms of Opportunity database; yet, of these, only 5 sightings (39 individuals) were belugas. Furthermore, approximately 19 beluga sightings (>260 individuals), possibly including resightings, have been reported without information on effort or other cetacean sightings. Of the 28 sightings of belugas outside of Cook Inlet, 9 were near Kodiak Island, 10 were in or near Prince William Sound, 8 were in Yakutat Bay, and 1 anomalous sighting was well south of the Gulf. These sightings support archaeological and commercial harvest evidence indicating the only persistent group of belugas in the Gulf of Alaska occurs in Cook Inlet.*

Historical Review

Prior to the 1970's

Prehistoric Native communities of the Gulf of Alaska may have harvested or scavenged belugas as part of their subsistence activities (de Laguna, 1956; Yarborough, 1995). The Alutiiq from the old village of Chenega in Prince William Sound were reported to have hunted large whales, which Birket-Smith (1953) surmised included sperm or humpback whales, as well as "little finners, white whales, blackfish and porpoises." According to Heizer (1947), petroglyphs on the cliffs of Cape Alitak, on Kodiak Island, Alaska, may depict cetaceans such as "the sperm whale, killer whale, and perhaps the porpoise or beluga." At least one village excavated on the northwestern coast of Kodiak Island yielded a few skeletal parts identified as beluga (Kellogg, 1936). However, cetacean bone samples collected from these communities are usually not identified by species because of fragmentation or deterioration (Yarborough, 1995). Instead, the bones are often categorized as "porpoise" (usually harbor porpoise, *Phocoena phocoena*) or "whale" (sometimes "small whale," "large whale," or "baleen whale") (de Laguna, 1956; Yarborough, 1995; McCartney, 1998), making it difficult to determine the extent to which prehistoric societies of the gulf relied on belugas.

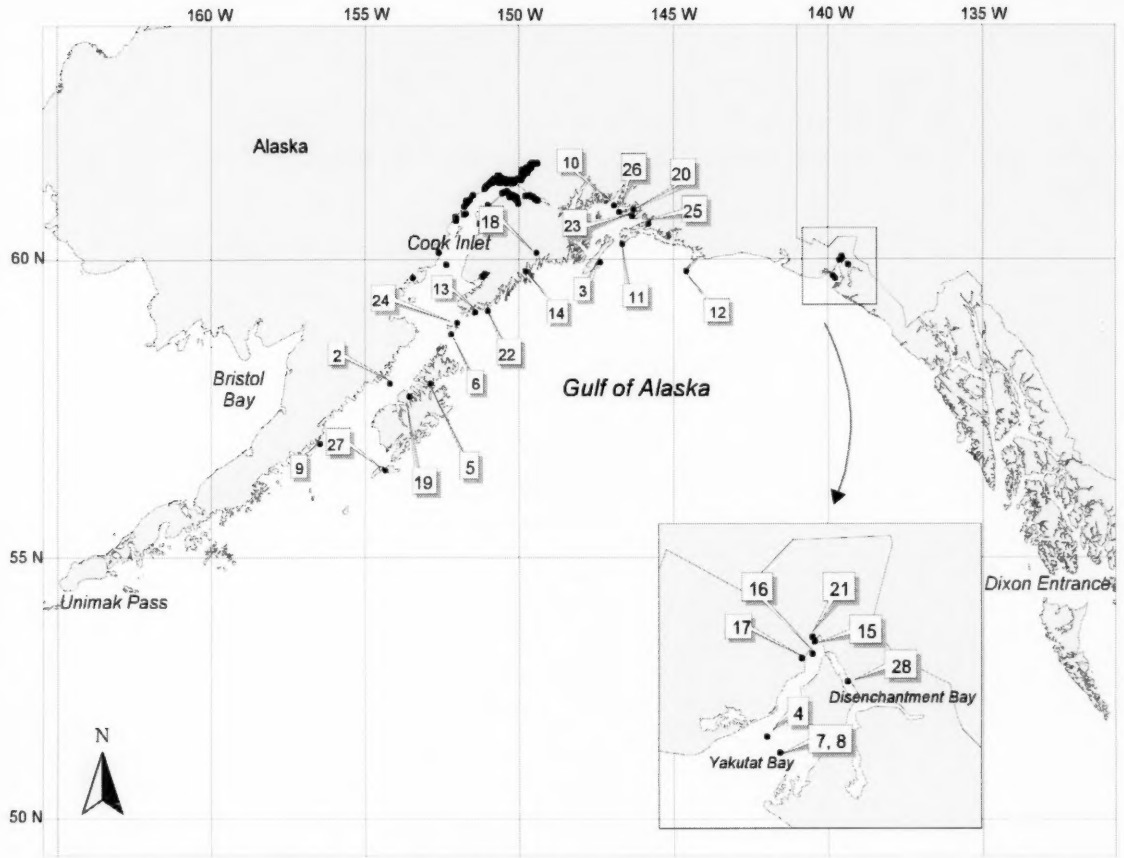

Figure 1.—Beluga sightings in the Gulf of Alaska. Sightings from 1993 to 2000 in Cook Inlet (Rugh et al., 2000) are shown but are not included in the sequence of map identification numbers in Table 1. The sighting (Map I.D. #1) in Washington is not shown on this map.

In general, whale bones represent only a small portion of the faunal remains identified in sites around Prince William Sound and Kodiak Island; porpoise bones, particularly bullae, were the greatest in number, but the majority of remains were from furbearing sea mammals (Kellogg, 1936; de Laguna, 1956; Yarborough and Yarborough, 1998).

During the modern era of commercial whaling, belugas were rarely targeted by whalers in the Gulf of Alaska, and only one of the commercial whaling stations operating between 1907 and 1939 reported harvesting or processing belugas (Tønnessen and Johnsen, 1982). The Beluga Whaling Company, founded in 1916 and based at the Beluga River in Cook Inlet, harvested 9 belugas from the Cook Inlet area in 1917, 42 in 1918, none in 1919, and 100 in 1920, after which the company went bankrupt (Bower and Aller, 1917, 1918; Bower, 1919, 1920, 1921).

In 1920, the U.S. Bureau of Biological Survey (BBS) was given the responsibility of enforcing Alaska fur laws, including the blue-fox, *Alopex lagopus*, industry in the Aleutian Islands, which required an extensive inventory of wildlife resources. This led to a biological survey in 1936 and 1937 covering most of the Aleutian Islands and the Alaska Peninsula. The ship-based survey included every island in the Aleutian chain, as well as islands south of the Alaska Peninsula and parts of Bristol Bay. Data were collected on invertebrate, bird, and mammal species sighted during the course of the survey. A report, prepared soon after the survey, was not published until 1959 (Murie, 1959). The report included qualitative descriptions of sightings and habitat. During the 2-year survey period, eight marine mammal species were observed: none were belugas. However, the report stated that the survey party was inexperienced at identifying cetaceans, and only the more easily identified species were considered positive sightings.

Dedicated Surveys

The 1970's

From November 1975 to April 1977, aerial surveys were flown over the Alas-

ka coastal and outer-continental-shelf waters (Harrison and Hall, 1978; Fig. 2). The surveys were designed to determine the seasonal distribution and abundance of marine mammals and birds. Approximately 40,000 km of trackline were surveyed in the Gulf of Alaska during January through October, with fairly intensive surveys occurring south of the Alaska Peninsula and extending from Kodiak Island west to the Aleutian Islands. All but 4 of the 35 belugas observed were seen in Cook Inlet. Those 4 were seen in March (1 whale) and July (2 whales) near Kodiak Island and in March (1 whale) near Prince William Sound (Table 1: Map I.D. no. 2, 3, 5). During the surveys, approximately 1,000 cetaceans were sighted, although the authors failed to list species (Harrison, 1979) other than belugas (Harrison and Hall, 1978).

A study of the breeding biology of avifauna in Prince William Sound was conducted from 28 April to 1 August 1976 (Nysewander and Knudtson[1]). The purpose of the study was to evaluate data on seabirds and shorebirds prior to the proposed petroleum developments in the area. Additional data were collected on marine mammal observations in the vicinity of this area. Six species of cetaceans were sighted; none were belugas.

Between May 1976 and October 1977, aerial and vessel surveys were conducted in Prince William Sound and the adjacent northern Gulf of Alaska (Hall[2]; Fig. 3) to document relative numbers, seasonal distribution, and major foraging grounds of cetaceans. The data were used by the Bureau of Land Management to evaluate the probable impacts on natural resources from development of petroleum reserves in Alaskan waters. No comprehensive studies of cetaceans in Prince William Sound had been conducted prior to this survey. Predetermined fixed transects were flown during the aerial portion of the study (3,970 km), and vessel survey tracklines (5,730 km) traversed areas that had been noted to have dense concentrations of cetaceans. Although 2,954 cetaceans were sighted during the surveys, none were belugas. However, belugas were included in a generalized table listing cetaceans reported from Prince William Sound (Table 1 in Hall[2]), but with no supporting references or data.

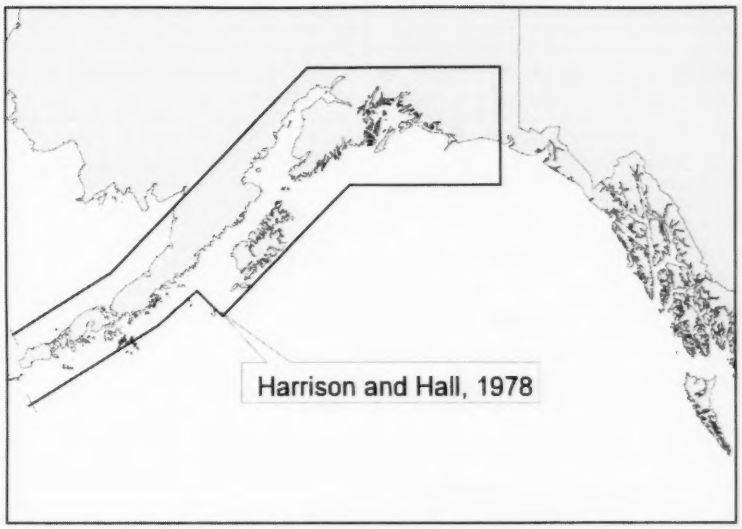

Figure 2.—Harrison and Hall (1978) marine mammal survey area.

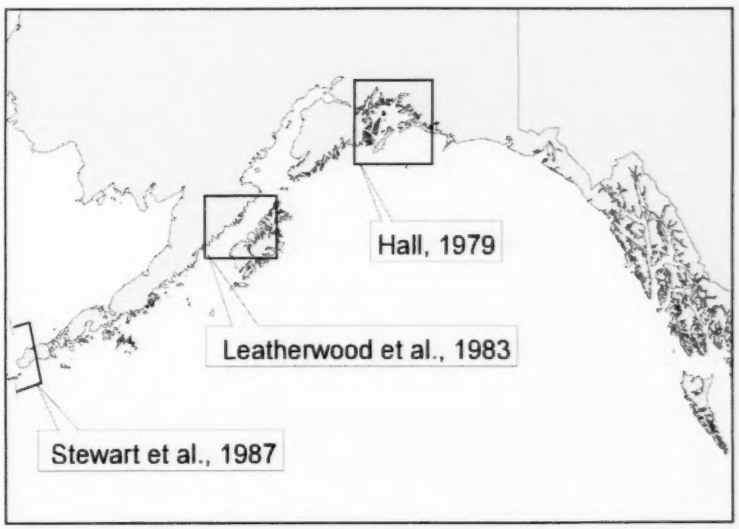

Figure 3.—Marine mammal survey areas of Hall (text footnote 2), Leatherwood et al. (text footnote 3), Stewart et al. (1987).

[1] Nysewander, D. R., and P. Knudtson. 1977. The population ecology and migration of seabirds, shorebirds and waterfowl associated with Constantine Harbor, Hinchinbrook Island, Prince William Sound, 1976. *In* J. C. Bartonek, C. J. Lensink, R. G. Gould, R. E. Gill, and G. A. Sanger (Editors), Population dynamics and trophic relationships of marine birds in the Gulf of Alaska and southern Bering Sea, Part IX, p. 500–575. Environ. Assessment Alaskan Cont. Shelf, Annu. Rep. 4, U.S. Dep Commer., Outer Cont. Shelf Assess. Program.

[2] Hall, J. D. 1979. A survey of cetaceans in Prince William Sound and adjacent vicinity—their numbers and seasonal movements. Environ. Assessment Alaskan Cont. Shelf, Final Rep. 6 (Biol. Stud.):631–726.

The 1980's

From February 1982 to March 1983, Leatherwood et al.[3] conducted a series of surveys for marine mammals in the eastern Bering Sea and Shelikof Strait (Fig. 3) to identify and describe habitat use by endangered whales. Distribution and abundance of marine mammals other than endangered whales was also documented. The Shelikof Strait study area (16,500 km^2) lies between Kodiak Island and the Alaska Peninsula and includes the southwest end of Cook Inlet. Surveyors flew 53,230 km, of which 5,524 km were in Shelikof Strait. During the eight survey periods, 1,649 marine mammal sightings were made during systematic survey effort, of which 305 were in Shelikof Strait. Although belugas were observed repeatedly in Cook Inlet during transit flights into and out of Anchorage, only one was seen outside of the inlet (Table 1: Map I.D. no. 9; Fig. 3).

[3] Leatherwood, S., A. E. Bowles, and R. R. Reeves. 1983. Aerial surveys of marine mammals in the southeastern Bering Sea. U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 42(1986):147–490.

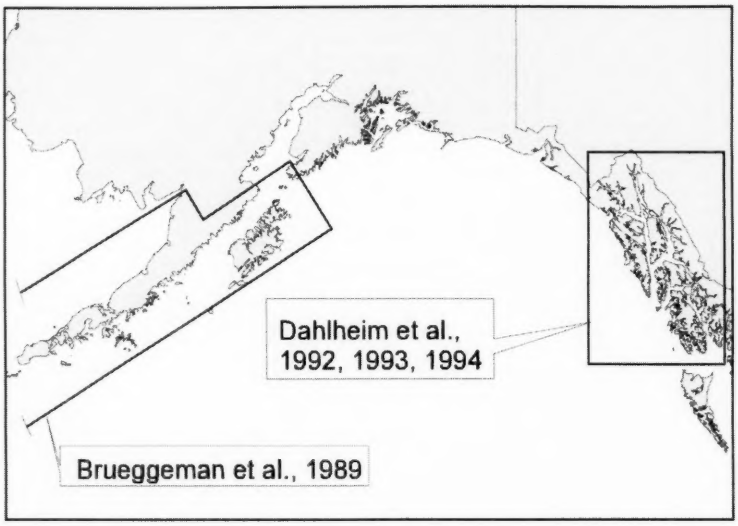

Figure 4.—Marine mammal survey areas of Dahlheim et al.(text footnotes 9,10,11), and Brueggeman et al.(text footnote 4).

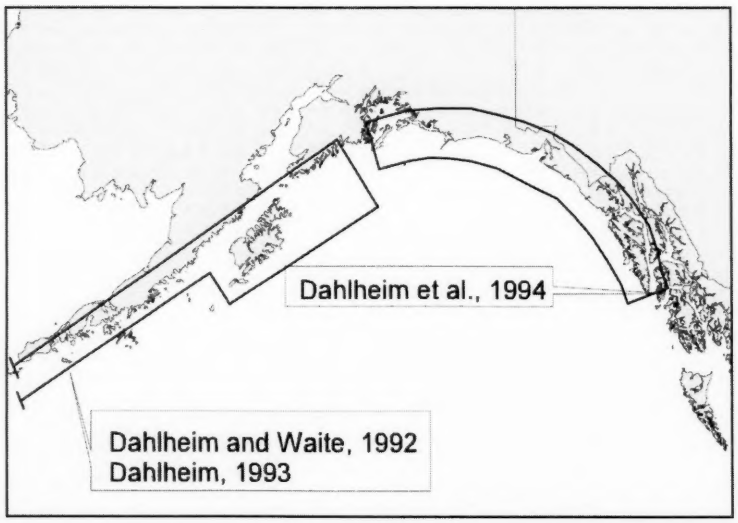

Figure 5.—Marine mammal survey areas of Dahlheim et al. (text footnote 11), Dahlheim and Waite (text footnote 6), and Dahlheim (text footnote 7) .

Between 26 July and 26 August 1984, aerial surveys were flown over the former Akutan whaling grounds north and south of Unimak Pass (Stewart et al., 1987; Fig. 3). The purpose of the survey was to search for cetaceans and to determine if low densities, which had been reported in the past, were artifacts of sparse coverage and poor survey conditions or were representative of the number of whales in the area. Surveys covered about 26,700 km^2 and were flown at the time of year when the greatest abundance of cetaceans was expected on the whaling grounds, based on historical records. There was a total of 78 cetacean sightings during systematic surveys and 24 cetacean sightings while transiting between Anchorage and Dutch Harbor. None of the sightings were belugas.

In 1985, 1986, and 1987, a series of surveys were conducted north and south of the Alaska Peninsula and in the eastern Aleutian Islands (Brueggeman et al.[4]; Fig. 4) to determine distribution, abundance, and habitat use patterns of endangered whales and other marine mammals. The 1985 aerial survey covered 74,000 km of trackline over the shelf, slope, and rise of the continental margin during seven periods between April and December. The 1986 aerial survey covered 33,300 km of trackline north and south of the Alaska Peninsula during four periods between March

[4] Brueggeman, J. J., G. A. Green, R. A. Grotefendt, R. W. Tressler, and D. G. Chapman. 1989. Marine mammal habitat use in the North Aleutian Basin, St. George Basin, and Gulf of Alaska. *In* L. E. Jarvela and L. K. Thorsteinson (Editors), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information Update Meeting, Feb. 7–8, 1989, Anchorage, Alaska, p. 97–108. OCS Study MMS 89-0041, U.S. Dep. Inter., Miner. Manage. Serv.

and October. However, the 1986 survey was specifically for sea otters, *Enhydra lutris*, and did not list cetacean sightings. The 1987 NOAA *Miller Freeman* vessel survey covered over 3,700 km of trackline south of the Alaska Peninsula during June and July. Of the 2,000 cetacean sightings made in 1985 and 1987, none were belugas.

Intermittently between 1984 and 1991, several thousand hours of aerial survey effort were conducted for sea otters between Yakutat Bay and the Kenai Peninsula (Monnett[5]). Survey effort was concentrated in the eastern half of Prince William Sound between 1987 and 1989 and the western half of the Sound between 1989 and 1991. Cetacean sightings were noted during these surveys; however, no belugas were seen.

The 1990's

In 1992, the National Marine Mammal Laboratory (NMML) of NOAA's National Marine Fisheries Service (NMFS) initiated a study of killer whales, *Orcinus orca*, in Alaska. A 45-day vessel survey covering 5,254 km was conducted in the Bering Sea and western Gulf of Alaska from 9 July to 22 August (Dahlheim and Waite[6]). The survey area focused on the central and eastern Aleutian Islands, southeastern Bering Sea, south side of the Alaska Peninsula, and the waters surrounding Kodiak Island (Fig. 5). The objectives of the survey were to obtain a minimum population estimate of killer whales using photo-identification techniques and to establish baseline data for detecting annual changes in abundance. Seven species of cetaceans were sighted during the survey, none of which were belugas. This survey was continued from 13 July to 24 August 1993 (43 days), covering 8,334 km in the eastern Aleutian Islands, southeastern Bering Sea, south side of the Alaska Peninsula, and Kodiak Island Archipelago (Dahlheim[7]; Fig. 5). Six species of cetaceans were sighted, and again, none were belugas.

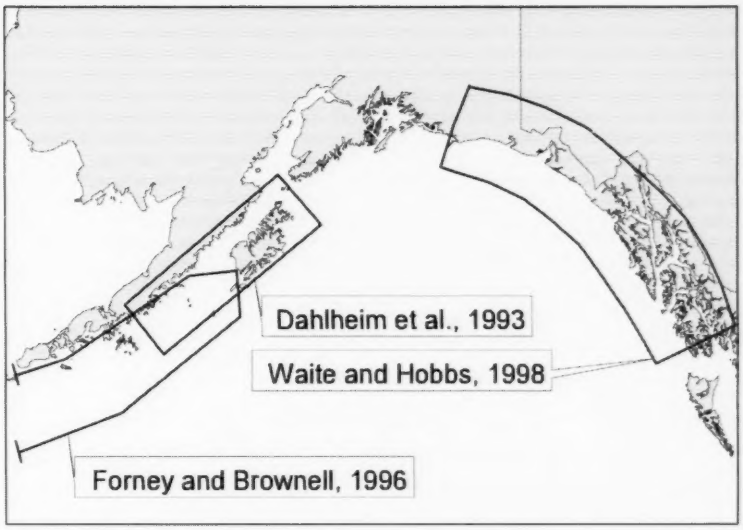

Figure 6.—Marine mammal survey areas of Dahlheim et al. (text footnote 10), Forney and Brownell (text footnote 12), and Waite and Hobbs (text footnote 14).

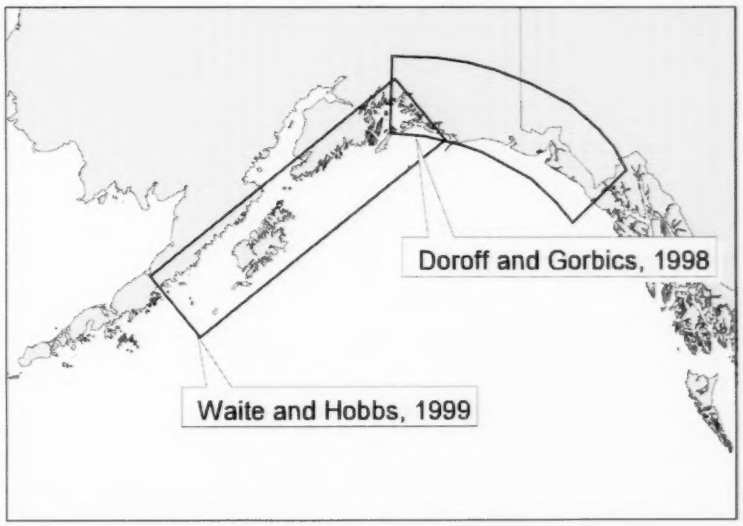

Figure 7.—Marine mammal survey areas of Doroff and Gorbics (text footnote 13) and Waite and Hobbs (text footnote 15).

During 1991–93, the NMML conducted a 3-year study of harbor porpoise to obtain minimum population estimates in Alaska coastal waters (Dahlheim et al., 2000). The survey area was divided into seven regions based on geographic considerations to facilitate

[5] Monnett, C. 1999. U.S. Dep. Inter., Miner. Manage. Serv. Anchorage, Alaska. Personal commun. via K. Laidre, on file at NMFS Natl. Mar. Mammal Lab., Seattle, Wash.

[6] Dahlheim, M. D., and J. M. Waite. 1992. Abundance and distribution of killer whales (*Orcinus orca*) in Alaska in 1992. Annu. Rep. to MMPA Assessment Program, Off. Protect. Resour., NMFS, NOAA, 1335 East-West Hwy., Silver Spring, MD 20910, 19 p.

[7] Dahlheim, M. D. 1993. Abundance and distribution of killer whales (*Orcinus orca*) in Alaska, 1993. Annu. Rep. to MMPA Assessment Program, Off. Protect. Resour., NMFS, NOAA, 1335 East-West Hwy., Silver Spring, MD 20910, 17 p.

Table 1.—Documented sightings of belugas in waters south and east of the Alaska Peninsula, excluding Cook Inlet. Some positions were approximated based on descriptive locations.

Map I.D. no.	Date	Location	Latitude Longitude	Group size	Source	Type[1]
1	4/23/40	Tacoma, Wash.	47°16′N 122°33′W	1	Scheffer and Slipp (1948)	I
2	7/16/75	Shelikof Strait, near Kodiak I.	58°00′N 154°11′W	2	Harrison and Hall (1978)	D
3	3/29/76	Montague Island, Prince William Sd.	59°57′N 147°22′W	1	Harrison and Hall (1978)	D
4	5/31/76	Yakutat Bay	59°45′N 139°50′W	21+5[2]	Fiscus et al.[3], Calkins and Pitcher[4]	P
5	3/83/77	Marmot Bay, between Kodiak and Afognak I.	58°00′N 152°52′W	1	Harrison and Hall (1978); also Consiglieri et al. (text footnote 16)	D
6	4/12/78	Barren Islands, north of Kodiak I.	58°48.9′N 152°11.9′W	3[5]	Consiglieri et al. (text footnote 16)	P
7	4/20/79	Yakutat Bay	~59°42′N 139°45′W	6	Mallot[6]	I
8	7/15/79	Yakutat Bay	~59°42′N 139°45′W	Several	Cox and Ranney[7]	I
9	8/6/82	SW entrance of Shelikof Strait, west of Kodiak I.	56°59.5′N 156°27.6′W	1	Leatherwood et al. (text footnote 3)	D
10	7/25/83	Near Bligh Island, Prince William Sd.	60°50′N 146°55′WI	200	Campbell (text footnote 18)	I
11	5/10/87	Cape Hinchinbrook, Prince William Sd.	60°14.07′N 146°38.08′W	1	NMML POP, unpubl. data[8]	P
12	5/11/87	Cape St. Elias off Kayak Island, Prince William Sd.	59°49.0′N 144°34.03′W	1	NMML POP, unpubl. data[8]	P
13	8/1/87	Between E. Chugach I. and the Kenai Pen., north of Kodiak I.	59°10.03′N 151°24.08′W	8	NMML POP, unpubl. data[8]	P
14	Summer 1988	Aialik Bay, at the entrance of Holgate Arm, Prince William Sd.	59°48.5′N 149°46.5′W	1[9]	NMFS 1992[10]	I
15	9/24/93	Disenchantment Bay, Yakutat Bay	60°02.10′N 139°32.10′W	2	Ream[11]	I
16	2/19/97	Disenchantment Bay, Yakutat Bay	60°01.5′N 139°33.1′W	10	Hubbard et al. 1999	I
17	8/20/97 to 8/25/97	W. of Disenchantment Bay, S. of Turner Glacier, Yakutat Bay	59°59.17′N 139°37.06′W	1–5[12]	Small and Lowry[13]	I
18	9/6/97	Resurrection Bay, Seward, near the shiplift, Prince William Sd.	60°06.55′N 149°25.68′W	6–8	Daley[14]	I
19	Winter 1997	W. Uganik Bay near Village Islands, Kodiak I.	57°47′N 153°33′W	1	Little[15]	I
20	8/9/98	St. Mathews Bay, Prince William Sound	60°46.3′N 146°16.9′W	1	Janka[16]	I
21	11/16/98 to 12/8/98	Disenchantment Bay, Yakutat Bay	60°03′N 139°33′W	6–11[17]	Molthen[18] and Howard[19]	I
22	7/14/99	Near tip of Gore Pt., East of Elizabeth I.	59°11′N 151°0′W	5	St. Peter[20]	I

Continued on facing page.

survey coverage (Fig. 4). Each of the seven areas was surveyed at least once over the 3-year period. Line-transects were covered by the NOAA ship *John N. Cobb* and a NOAA Twin Otter[8]. In 1991, three vessel surveys were completed in the inside waters of southeastern Alaska (20 April–3 May, 15–25 July, and 12–19 September), with aerial surveys completed in 1991 in Cook Inlet (1–2 August) (Dahlheim et al.[9]). In 1992, vessel surveys were conducted in southeastern Alaska (29 April–12 May, 11–23 June, and 10–24 September) and aerial surveys were conducted off Kodiak Island and the south side of the Alaska Peninsula (6 July–9 August) (Dahlheim et al.[10]). In 1993, vessel surveys were completed in the inside waters of southeastern Alaska (30 April–13 May, 7–20 June, and 22 September–3 October) and aerial surveys in the offshore waters from Dixon Entrance to Prince William Sound (1–26 June) (Dahlheim et al.[11]). Over the 3-year survey period, nine species of cetaceans were identified; however, with

[8] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

[9] Dahlheim, M. D., A. E. York, J. M. Waite, and C. Goebel-Diaz. 1992. Abundance and distribution of harbor porpoise (*Phocoena phocoena*) in southeast Alaska, Cook Inlet, and Bristol Bay, Alaska. Annu. Rep. to MMPA Assessment Program, Off. Protect. Resour., NMFS, NOAA, 1335 East-West Hwy., Silver Spring, MD 20910, 26 p.

[10] Dahlheim, M. D., A. E. York, J. M. Waite, and R. Towell. 1993. Abundance and distribution of harbor porpoise (*Phocoena phocoena*) in southeast Alaska and the western Gulf of Alaska, 1992. Annu. rep. to MMPA Assessment Program, Off. Protect. Resour., NMFS, NOAA, 1335 East-West Hwy., Silver Spring, MD 20910, 13 p.

[11] Dahlheim, M. D., A. E. York, J. M. Waite, and R. Towell. 1994. Abundance and distribution of harbor porpoise (*Phocoena phocoena*) in southeast Alaska and the offshore waters of Dixon Entrance to Prince William Sound, 1993. Annu. Rep. to MMPA Assessment Program, Off. Protect. Resour., NMFS, NOAA, 1335 East-West Hwy., Silver Spring, MD 20910, 25 p.

Table 1.—Continued.

Map I.D. no.	Date	Location	Latitude Longitude	Group size	Source	Type[1]
23	7/27/99	Simpson Bay, Prince William Sound	60°40'N 146°20'W	1	Dodge[21]	I
24	8/1/99	Barren Is.	59°00'N 152°00'W	1	Rutledge[22]	I
25	9/3/99	Simpson Bay, Prince William Sound	60°33'N 145°48'W	1	Anderson[23]	I
26	9/4/99	Goose I., Prince William Sound	60°44'N 146°45'W	1	Matkin[24]	I
27	8/00 to summer 2001	Alitak Bay, south end of Kodiak I.	56° 32'N 154° 20'W	1	Wynne and Lord[25]	I
28	8/14/00 to 8/15/00	Bancas Pt. and Russell Fjord, Yakutat Bay	59° 55'N 139° 20'W	6 (4–8)	Herter and Plafker[26]	I

[1] D = dedicated marine mammal survey with records of effort and other cetaceans seen; P = sighting of a beluga on a survey without dedicated effort (e.g. sightings from the POP database); I = incidental beluga sighting without effort information.

[2] Fiscus et al. (1976) report the sighting as 21 adults and 5 subadults (cited as personal commun. from D. Calkins) while Calkins and Pitcher (1977) only report 21 animals.

[3] Fiscus, C. H., H. W. Braham, and R. W. Mercer. 1976. Seasonal distribution and relative abundance of marine mammals in the Gulf of Alaska. p. 19-264. Final Rep. Outer Continental Shelf Environ. Assessment Program, U.S. Dep. Inter., Bur. Land Manage.

[4] Calkins, D., and K. Pitcher. 1977. Unusual sightings of marine mammals in the Gulf of Alaska. *In* Abstracts of the Second Conference on the Biology of Marine Mammals, San Diego, CA, 12–15 December 1977, p. 53.

[5] Comment in POP database states "slate gray, young".

[6] Mallot, B. 1979. Personal commun. ADFG records, Anchorage.

[7] Cox, D., and G. Ranney. 1979. Personal commun. ADFG records, Anchorage.

[8] Laidre, K. L., and S. A. Mizroch. 1997. Geographic distribution of marine mammals in the North Pacific Ocean, National Marine Mammal Laboratory, 1958–1995. Unpubl. NMML data, 17 p.

[9] Reported by sport fishermen. Color photographs show the animal to be a subadult milling around several boats. No other belugas were observed in the vicinity.

[10] NMFS. 1992. Status report on Cook Inlet belugas (*Delphinapterus leucas*). Unpubl. doc. prep. by NMFS Alaska Reg. Off., 222 West 7th Ave., #43, Anchorage, AK 99513, 22 p.

[11] Ream, R. 1993. National Marine Mammal Lab., NMFS, NOAA. Personal commun. via D. Rugh, NMML, NMFS, Seattle, Wash.

[12] According to R. Small, Native hunters report seeing belugas in the area year round. Sightings on the 20 and 21 Aug. included large white animals only.

[13] Small, R., and L. Lowry. 1997. Alaska Dep. Fish Game, Anchorage, Alaska. Personal commun. via D. Rugh, NMML, NMFS, Seattle, Wash. This sighting includes four resightings of the same group. This group was also seen by Bert Adams, Sr. (Yakutat Tribal President) in July 1997.

[14] Daley, N. 1997. Personal commun. via C. Matkin to B. Mahoney, NMFS Alaska Reg. Off., Anchorage.

[15] Little, D. 1997. Personal commun. via B. Mahoney, NMFS, Alaska Reg. Off., Anchorage.

[16] Janka, D. 1998. National Marine Fisheries Service, AKR. Personal commun. via B. Mahoney, NMFS, Alaska Reg. Off., Anchorage.

[17] Whales were in pancake ice and in the same location on both days. Several large white adult whales were observed in the group. No whales were observed on 8 Dec. when heavier ice was in the area However, Lt. K. Howard, USCG, reported 10–11 whales (3 of which were gray) on 16 Nov., 3 Dec., and 8 Dec. in a small cove northwest of Brady Glacier (personal commun. to B. Smith, NMFS, Alaska Reg. Off., Anchorage), possibly the same group observed by D. Molthen.

[18] Molthen, D. 1998. United States Coast Guard. Personal commun. via S. Moore, NMML, NMFS, Seattle, Wash.

[19] Howard, K. 1998. United States Coast Guard. Personal commun. via B. Mahoney, NMFS, Alaska Reg. Off., Anchorage.

[20] St. Peter, J. 1999. Personal commun. via B. Mahoney, NMFS, Alaska Reg. Off., Anchorage.

[21] Dodge, B. 1999. Prince William Sound Science Center. Personal commun. via B. Mahoney, NMFS, Alaska Reg. Off., Anchorage.

[22] Rutledge, A. 1999. Personal commun. via B. Mahoney, NMFS, Alaska Reg. Off., Anchorage.

[23] Anderson, P. 1999. Charter boat operator, Cordova, AK. Personal commun. via D. Rugh, NMML, Seattle, Wash.

[24] Matkin, C. 1999. P. O. Box 15244, Homer, AK 99603. Personal commun. via D. Rugh, NMML, Seattle, Wash.

[25] Wynne, K. 2000. Univ. Alaska Fairbanks, Kodiak, AK, and N. Lord, journalist. Personal commun. via B. Mahoney, NMFS Alaska Reg. Off., Anchorage. A young, lone beluga was seen in Alitak Bay intermittently between August 2000 and summer 2001 (at the time of this writing). It seemed to be quite tame and had a propellor-like scar on its back.

[26] Herter, M., and G. Plafker. 2001. U.S. Geological Survey. Personal commun. via L. Jemison, Alaska Dept. of Fish and Game, Anchorage, AK.

the exception of Cook Inlet, there were no beluga sightings in any of the seven survey regions (Dahlheim et al.[9,10,11]).

In August 1994, a vessel survey was conducted south of the Aleutian Islands to assess abundance and distribution of large whales in historical whaling grounds (Forney and Brownell[12]) (Fig. 6). The survey covered 3,797 km of trackline, but this included areas well west of Unimak Pass. Eight species of cetaceans were sighted during the survey, but none were belugas.

In August of 1995 and 1996, aerial surveys were conducted in the Gulf of Alaska to determine the distribution of sea otters along the outer coast and their abundance within Yakutat Bay (Doroff and Gorbics[13]). The first survey was conducted from Cape Suckling to Cape Spencer during 8–9 August 1995 (Fig. 7). The second survey was conducted from Cape Hinchinbrook to Cape Suckling during 19–23 August 1996. Of 907 marine mammal sightings, no belugas were recorded in either year.

In 1997, the NMML began a series of surveys conducted over a 3-year period to estimate abundances of harbor porpoise, Dall's porpoise, *Phocoenoides dalli*, and Pacific white-sided dolphins, *Lagenorhynchus obliquidens* (Waite and Hobbs[14,15]). Between 27 May and 28 July 1997, 53 survey hours covered parts

[12] Forney, K. A., and R. L. Brownell. 1996. Preliminary report of the 1994 Aleutian Island Marine Mammal Survey. Pap. SC/48/O11 pres. to IWC Sci. Committee 1996, 9 p.

[13] Doroff, A., and C. Gorbics. 1998. Sea otter surveys of Yakutat Bay and adjacent Gulf of Alaska coastal areas—Cape Hinchinbrook to Cape Spencer 1995–1996. Final Rep. to Minerals Manage. Serv., 949 E. 36th Ave. Suite 300, Anchorage, AK 99503. OCS Study MMS 97-0026, 45 p.

[14] Waite, J. M., and R. C. Hobbs. 1998. Small cetacean aerial and vessel survey in southeast Alaska and the eastern Gulf of Alaska, 1997. *In* P. S. Hill, B. Jones, and D. P. DeMaster (Editors), Marine Mammal Protection Act and Endangered Species Act Implementation Program, 1997, p. 23–35, U.S. Dep. Commer., NOAA, Natl. Mar.

Continued on next page.

of southeastern Alaska and the eastern Gulf of Alaska from Dixon Entrance to Cape Suckling, including Yakutat Bay (Fig. 6). A concurrent vessel survey was conducted in Glacier Bay and Icy Strait aboard the NOAA ship *John N. Cobb*. The vessel survey totaled 45 hours and was conducted 31 May–5 June. In 1998, from 27 May to 28 July, aerial surveys included Prince William Sound and the Gulf of Alaska from Cape Suckling to the Alaska Peninsula as far as the Semidi Islands, including Shelikof Strait (Waite and Hobbs[15]) (Fig. 7). The western end of the Alaska Peninsula was surveyed in 1999 as a part of the survey in Bristol Bay. In these three years, 846 marine mammal sightings were made during the aerial surveys in the Gulf of Alaska and adjacent waters, and 303 sightings were made during the vessel survey, but there were no sightings of beluga whales in this area, including the survey in Yakutat Bay under excellent conditions. The only belugas that were seen were in Bristol Bay and Cook Inlet.

In September 1999, aerial surveys were begun to document the seasonal distribution of Steller sea lions, *Eumetopias jubatus*, and cetaceans around the Kodiak Archipelago (Wynne[16]). These surveys were flown once a month, each usually taking 4 h to complete. Approximately 12 h were flown in 1999 and 48 h in 2000. Wynne[16] also reported flying a repetitive series of surveys (4.5 hours for each of 7 or 8 flight-days per year) each August since 1992, looking for harbor seals, *Phoca vitulina*, in the Kodiak vicinity. All cetacean sightings were reported for these surveys (7 species), but no belugas were seen.

Opportunistic Records

Platforms of Opportunity Program

In addition to the marine mammal sightings reported during dedicated surveys (listed above), the NMFS maintains a database of marine mammal observations collected during both dedicated and opportunistic surveys. Sightings made in the Gulf of Alaska between 1958 and 1980, including incidental observations reported to the NMFS Platforms of Opportunity Program (POP), were summarized by Consiglieri et al.[17]. The report provided an overview of seasonal distribution and relative abundance of marine mammals in the Gulf of Alaska. Data were gathered from four sources: 1) the NMML Dall's Porpoise Research Program (operated from NOAA and U.S. Coast Guard ships from 1975 to 1980); 2) the NMML pelagic fur seal, *Callorhinus ursinus*, program (1958 to 1974); 3) an Outer Continental Shelf Environmental Assessment Program (OCSEAP) dedicated summer vessel cruise in 1980; and 4) POP observers on NOAA or other ships. Forty percent of the POP database consisted of sightings with quantified effort, most of which occurred after 1975. Laidre and Mizroch[18] updated the listing of marine mammal sightings to include POP records collected through 1995 (Fig. 1). Sighting data are from the entire Gulf, extending north from lat. 54°N to the Alaska coast and from long. 133°W to 157°W, inclusive of all data collected from 1958 to 1995. Of the 141 beluga sightings in the POP database, only 5 (39 belugas) occurred in the Gulf of Alaska (Table 1: Map I.D. no. 4, 6, 11, 12, 13).

In addition to the 4 beluga sightings that occurred during dedicated marine mammal surveys and the 5 sightings from opportunistic studies without known effort, there were 19 incidental records without any information on effort or other cetaceans seen. For example, beluga sightings reported from commercial or recreational fishing boats, tourists, and bird surveys have been included here; however, this network of information cannot be evaluated in terms of the amount of time spent searching for animals that may have resulted in a beluga sighting.

The first incidental sighting in this record, a beluga seen near Tacoma, Washington, in April 1940 (Scheffer and Slipp, 1948), is anomalous, though the sighting was well documented and seems credible (Table 1: Map I.D. no. 1). The approximate distance from upper Cook Inlet is well over 2,500 km, similar to the distance belugas are known to swim annually from the ice front in the Bering Sea to the Beaufort Sea.

In these records, there was only one sighting of more than 30 beluga whales at a time, other than in Cook Inlet where 200–400 are seen regularly (Rugh et al., 2000): a report of 200 belugas in Prince William Sound on 25 July 1983 (Campbell[19]; Table 1: Map I.D. no. 10). Note that in the same year in Cook Inlet, 262 belugas were counted on 27 May, 13 belugas on 24 June, and 176 belugas on 20 July (Calkins[20]). This unusual record occurred during a season following a particularly strong El Niño event (Enfield, 1989) which may have affected fish distribution.

Summary and Conclusions

Very few dedicated marine mammal surveys were conducted in the Gulf of Alaska prior to the 1970's. Since then marine mammal survey effort has intensified, yet reported sightings of belugas have not increased. During the 13 well documented surveys reported here, over 23,000 cetaceans were seen; however,

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[14] *(cont.)* Fish. Serv., Alaska Fish. Sci. Cent. Proc. Rep. 98–10.

[15] Waite, J. M., and R. C. Hobbs. 1999. Small cetacean aerial survey in Prince William Sound and the western Gulf of Alaska in 1998 and preliminary harbor porpoise abundance estimates for the southeast Alaska and the Gulf of Alaska stocks. *In* A. L. Lopez and D. P. DeMaster (Editors), Marine Mammal Protection Act and Endangered Species Act Implementation Program, 1998, p. 39–53, U.S. Dep. Commer., NOAA, Natl. Mar. Fish. Serv., Alaska Fish. Sci. Cent. Proc. Rep. 99–08.

[16] Wynne, K. 2000. University of Alaska Fairbanks, Kodiak, Alaska. Personal commun. via D. Rugh, on file at NMFS Natl. Mar. Mammal Lab., Seattle, Wash.

[17] Consiglieri, L. D., H. W. Braham, M. E. Dahlheim, C. Fiscus, P. D. McGuire, C. E. Peterson, and D. A. Pippenger. 1982. Seasonal distribution and relative abundance of marine mammals in the Gulf of Alaska. Final Rep., p. 189–280. Outer Cont. Shelf Environ. Assessment Program, U.S. Dep. Inter., Bur. Land Manage.

[18] Laidre, K. L., and S. A. Mizroch. 1997. Database modifications and data analysis for the Platforms of Opportunity Program at the National Marine Mammal Laboratory, 1958–1995. Unpubl. doc., 13 p., on file at NMFS Natl. Mar. Mammal Lab., Seattle, Wash.

[19] Campbell, B. 1999. Oregon State Dep. Fish Wildl., Springfield. Personal commun. via K. Shelden, on file at NMFS Natl. Mar. Mammal Lab., Seattle, Wash.

[20] Calkins, D. G. 1984. Belukha whale. Vol. IX of Susitna hydroelectric project; final report; big game studies. Alaska Dep. Fish Game., Doc. 2328, 17 p.

only 5 were belugas (4 sightings) (Harrison and Hall, 1978; Leatherwood et al.[3]; and Table 1). Of the surveys conducted in the Gulf of Alaska reported in the POP database, nearly 100,000 cetaceans were seen (Table 2). Of these, 1,789 (141 sightings) were belugas; however, only 39 (5 sightings) were outside of Cook Inlet. Furthermore, approximately 260 belugas (19 sightings) have been reported without information on effort or other cetacean sightings. Compared to the thousands of other cetaceans that have been reported, these 28 sightings collected over two decades indicate belugas are relatively rare in the Gulf of Alaska outside of Cook Inlet. In contrast, belugas have been recorded on virtually every survey for whales in Cook Inlet; for example, Klinkhart's [21] two surveys in 1963–64; Murray and Fay's[22] survey in August 1978; Calkins'[23] seven surveys in most months of the years 1974–79; Calkins'[20] two surveys in April through August 1982–83; the Hansen and Hubbard[24] surveys February through March 1997; and the nine June/July surveys by Rugh et al. (2000) during 1993–2000.

The beluga sightings in the Gulf of Alaska (Table 1, Fig. 1) occurred in three general areas: 9 were seen near Kodiak Island (including sightings west of Kodiak and east to the Kenai Peninsula); 10 were from Prince William Sound and east to Kayak Island (generally sightings of only a single animal each, Fig. 8); 8 were from Yakutat Bay; and 1 anomalous sighting was from south of the Gulf. In Table 1, there were only three reports of belugas in Yakutat Bay in the 1970's, but fishermen recalled often seeing 10–20 belugas there during this same time (Morris et al., 1983). There were no subsequent reports of belugas in Yakutat Bay until the 1990's. This may either be due to the lack of a mechanism to report sightings or to the lack of belugas; however, geologists with the U.S. Geological Service who have spent part of each summer in Yakutat Bay since 1964 never saw belugas there until August 2000 (Table 1). In 1997–98, several sightings of 5–10 animals were reported, including multiple sightings within a week of each other (Table 1). Notably, the Yakutat sightings occurred in all seasons of the year. However, these sightings were noncontiguous; therefore, they do not indicate that these whales are a resident population. These belugas are considered to be occasional visitors from Cook Inlet—only 1,000 km away—rather than permanent residents (Calkins[25]; Hubbard et al., 1999; Huntington, 2000) because many dedicated surveys in this area have not found belugas (Fig. 2–7). Currently, there is no satisfactory evidence to determine whether these whales are part of the Cook Inlet stock or whether they are a separate population.

The apparent geographic isolation of belugas in Cook Inlet is supported by mitochondrial DNA analyses which show distinct differences between Cook Inlet belugas and the other four stocks of belugas in Alaska (O'Corry-Crowe

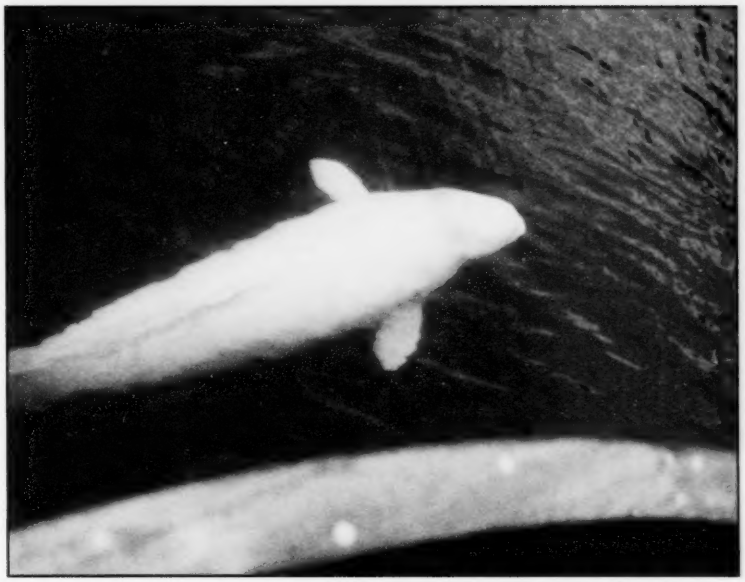

Figure 8.—Beluga whale seen in Prince William Sound on 9 August 1998. Photo by Dave Janka (Table 1 footnote 16).

Table 2.—Sightings of marine mammals in the Gulf of Alaska (excluding Cook Inlet) from the reported literature in this review where sightings are listed by species. Number of individuals is a minimum because some authors only reported number of sightings. This table does not include beluga sightings reported without information on effort or other cetacean sightings.

Marine mammal	Individuals
Dolphin and porpoise	55,897
Medium-sized cetacean	9,111
Large whale	19,814
Pinniped	64,677
Unidentified cetacean	14,485
Unidentified pinniped	5,522
Beluga	44
Total	169,550

[21] Klinkhart, E. G. 1966. The beluga whale in Alaska. State of Alaska Dep. Fish Game, Juneau, Fed. Aid Wildl. Restor. Proj. Rep. Vol. VII, Proj. W-6-R and W-14-R, 11 p.

[22] Murray, N. K., and F. H. Fay. 1979. The white whales or belukhas, *Delphinapterus leucas*, of Cook Inlet, Alaska. Pap. SC/31/SM12 pres. to IWC Sci. Committee, June 1979, 7 p.

[23] Calkins, D. G. 1979. Marine mammals of lower Cook Inlet and the potential for impact from Outer Continental Shelf oil and gas exploration, development and transport. Alaska Dep. Fish Game, 333 Raspberry Rd., Anchorage, 89 p.

[24] Hansen, D. J., and J. D. Hubbard. 1998. Distribution and abundance of Cook Inlet beluga whales (*Delphinapterus leucas*) in winter. U.S. Dep. Inter., Bur. Land. Manage., Minerals Management Serv., Environ. Stud. Sec., Alaska OCS Reg., 949 East 36th Ave., Anchorage AK 99508-4363, Draft Final Rep., 34 p.

[25] Calkins, D. G. 1989. Status of belukha whales in Cook Inlet. *In* L. E. Jarvela and L. K. Thorsteinson (Editors), Proceedings of the Gulf of Alaska, Cook Inlet, and North Aleutian Basin Information Update Meeting, Feb. 7–8, 1989, Anchorage, Alaska, p. 109–112. OCS Study MMS 89-0041, U. S. Dep. Inter., Bur. Land. Manage., Minerals Manage. Serv.

et al., 1997). This high degree of genetic discreteness indicates there has been a long and consistent isolation of belugas in the waters of Cook Inlet. The paucity of belugas outside of Cook Inlet is further supported by archeological evidence, commercial whaling records, and marine mammal surveys. Although scattered sightings led to speculation that belugas may range along the northern part of the Gulf of Alaska (Murray and Fay[22]), overwhelming evidence supports our conclusion that the only persistent group of belugas in the Gulf of Alaska is in Cook Inlet.

Acknowledgments

Sue Moore provided guidance as Program Leader of the Cetacean Assessment and Ecology Program. Janice Waite synthesized information on recent survey dates and sighting data in the Gulf of Alaska. We are deeply grateful to the observers who provided sighting information used in Table 1. Document reviews were provided by Sue Moore, Janice Waite, and Marilyn Dahlheim of the National Marine Mammal Laboratory, by Gary Duker and Jim Lee of the Alaska Fisheries Science Center Publications Unit, and by three anonymous reviewers. Special thanks to D. Janka for providing a photograph of his beluga sighting.

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Abundance of Belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska, 1994–2000

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Introduction

Beluga, *Delphinapterus leucas*, abundance in Cook Inlet has been estimated by several authors in the past three decades to be in the range of 300–1300 whales (reviewed in Rugh et al., 2000). In some cases, those were the sums of maximum visual counts and therefore represent minimum estimates. In other cases, estimates of total abundance were made by multiplying the counts by ad hoc correction factors to account for whales that were presumed to have been missed. None of these earlier surveys were designed specifically to estimate total abundance of belugas in Cook Inlet, but they have provided useful information on distribution, behavior, ecology, and minimum abundance.

Drawing on the observations and insights from those studies, we designed a survey to estimate absolute abundance of Cook Inlet belugas. Accurate abundance estimates depend on:

1) Repeated systematic surveys for beluga groups throughout their known range, and counts of each group seen (Rugh et al., 2000).
2) Corrections for whales that were missed during the counts (Hobbs et al., 2000), in particular for: A) whales that never surfaced during the count (availability bias); and B) whales that surfaced but were missed during the count (detection bias).
3) Corrections for whales not counted because the entire group was not detected by observers during one or more surveys (calculated in this report).

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ABSTRACT—Annual abundance estimates of belugas, Delphinapterus leucas, *in Cook Inlet were calculated from counts made by aerial observers and aerial video recordings. Whale group-size estimates were corrected for subsurface whales (availability bias) and whales that were at the surface but were missed (detection bias). Logistic regression was used to estimate the probability that entire groups were missed during the systematic surveys, and the results were used to calculate a correction to account for the whales in these missed groups (1.015, CV = 0.03 in 1994–98; 1.021, CV = 0.01 in 1999–2000). Calculated abundances were 653 (CV = 0.43) in 1994, 491 (CV = 0.44) in 1995, 594 (CV = 0.28) in 1996, 440 (CV = 0.14) in 1997, 347 (CV = 0.29) in 1998, 367 (CV = 0.14) in 1999, and 435 (CV = 0.23, 95% CI=279–679) in 2000. For management purposes the current* N_{best} = 435 *and* N_{min} = 360. *These estimates replace preliminary estimates of 749 for 1994 and 357 for 1999. Monte Carlo simulations indicate a 47% probability that from June 1994 to June 1998 abundance of the Cook Inlet stock of belugas was depleted by 50%. The decline appears to have stopped in 1998.*

Background

During late spring and early summer, dense aggregations of belugas are found near river mouths along the shores of upper Cook Inlet (Rugh et al., 2000). Very few belugas have been seen outside of Cook Inlet in the Gulf of Alaska (Laidre et al., 2000), and in recent years during June or July, belugas have become rare except near shore in the upper inlet (Rugh et al., 2000). Large tidal fluctuations in Cook Inlet (>10 m) and broad tidal flats (>7 km across) result in strong currents and significant changes in the shoreline through each tidal cycle. Belugas move with these tidal fluctuations to remain in fairly shallow water, perhaps to optimize feeding opportunities on fish runs (Huntington, 2000; Moore et al., 2000).

Observed behavior within a group may vary from nondirectional milling to traveling rapidly in a closely packed, unidirectional manner, to resting at the surface. Because the waters in upper Cook Inlet are extremely turbid and essentially opaque, any part of a beluga that is below the surface is out of sight. When at the surface, belugas appear as white or gray ovals against a brown background of water. The white adult whales contrast with the water, which makes them easy to see even at a distance; however, the gray color of young belugas is harder to detect. Water disturbance incurred when whales come to the surface to breathe can serve as a sighting cue, albeit a subtle one.

Field Methods

Aerial surveys were designed to take advantage of the highly aggregated population of belugas seen near river mouths and relatively good weather and visibility in June and July. Survey protocol involved systematic searches of all coastal areas (within 3 km of the waterline) around Cook Inlet (1,350 km), where virtually all belugas are found during these months, as well as flying 500 to 1,500 km of sawtooth transects across the middle of the inlet to search for whales beyond 3 km from shore (Rugh et al., 2000).

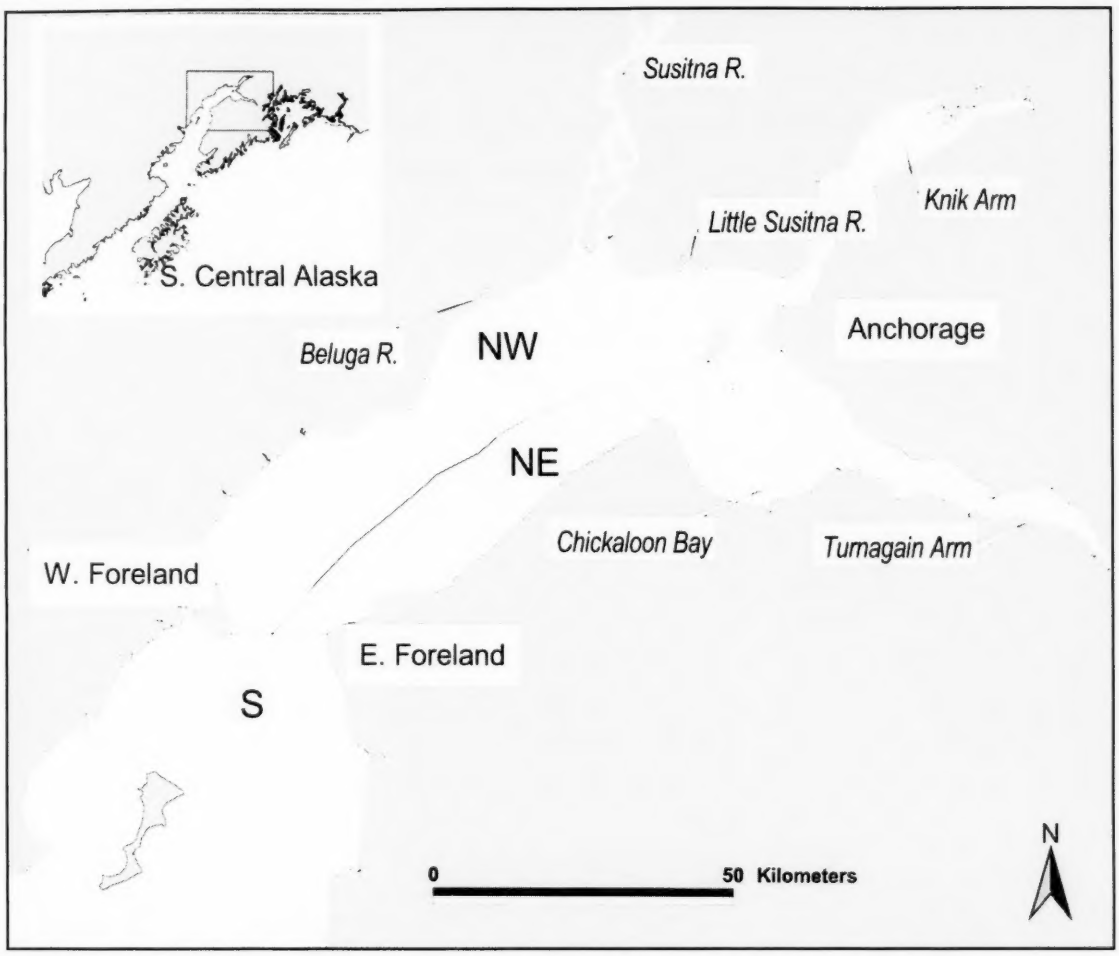

Figure 1.—Cook Inlet, in south-central Alaska, divided into three geographical sections for this report: 1) Northwest (West Foreland to Anchorage); 2) Northeast (Anchorage to East Foreland); and 3) South (lower Cook Inlet, south of the Forelands).

When possible, visual and auditory isolation was maintained between observers to allow independent search effort. This independent search was interrupted during weather checks and when circling groups. When groups were found, repeated counts were made using an extended racetrack flight pattern, such that observers always counted and video-recorded groups on the same side of the aircraft while passing them on a straight line. Generally, each observer had 4 opportunities to count each whale group encountered on each survey day.

Because the upper inlet was surveyed 2–4 times each year, there were many resightings of groups of the same whales seen on different days. To account for these resightings in the following analysis, whales in Cook Inlet were considered to be from one of three geographical sections: 1) Northwest (from West Foreland to Anchorage, including Beluga River, the Susitna Rivers, and Knik Arm); 2) Northeast (from Anchorage to East Foreland, including Turnagain Arm and Chickaloon Bay); and 3) South (anywhere south of the Forelands down to the mouth of Cook Inlet; Fig. 1). This subdivision of Cook Inlet assumed that whales may move within a section but not between sections from one survey day to the next during the survey period (3–9 days per year). Consistency in sighting locations have been evident in the multiple surveys conducted each year from 1993 to 2000 (Rugh et al., 2000) and from a whale that provided location data daily through the summer of 1999 (Ferrero et al., 2000).

Analysis Methods

Group-size estimates were available either from the analysis of video record-

ings or from observers' aerial counts corrected for missed whales (Table 1; Hobbs et al., 2000). Also estimated is the fraction of the total population of whales that were in groups not seen during the aerial surveys (see "Correction for Missed Groups" below). Group sizes were then summed to estimate abundance within each geographical section for each survey day. These daily abundances were averaged to estimate annual abundance in each section. Finally, the sectional abundances were summed to calculate total annual abundance.

Correction for Missed Groups

The fraction of the total population of belugas in groups that were missed during systematic surveys was estimated from the paired, independent records of primary observers on the shoreward side of the aircraft. Iterative logistic regression with an offset (Buckland et al., 1993:288–289) was used to estimate the probability of detection associated with each recorded whale group. Possible covariates were position in the aircraft (front or middle), group size, observer, sea state, and visibility.

Once the matching record was established, all covariates were examined individually as binned categorical data. Functional forms were chosen or bins were combined to represent the data with as few parameters as possible. All covariates were then entered into the model, and a backward step-wise model selection was followed until no step decreased the Akaike Information Criterion (AIC). The logistic regression model was used to estimate p_g, the probability that the gth group was detected by at least one observer:

$$p_g = 1-(1-p_{gf})(1-p_{gm}),$$

where p_{gf} and p_{gm} are the probability of detection by the front and middle observers, respectively. The correction for the fraction of whales in missed groups, $\hat{K}$, was a weighted average (Seber, 1973) of the inverse of the estimated probability of detection of each group (to account for the possibility that a group of similar size was missed) using the estimated group size for each group as the weight:

$$\hat{K}_y = \frac{\sum_{g=1}^{J_y} \frac{\hat{n}_g}{p_g}}{\sum_{g=1}^{J_y} \hat{n}_g},$$

$$CV(\hat{K}_y) = \frac{1}{\hat{K}_y}\sqrt{\frac{\sum_{g=1}^{J_y}\left[\hat{n}_g\left(\hat{K}_y - \frac{1}{p_g}\right)^2\right]}{(J_y-1)\sum_{g=1}^{J}\hat{n}_g}},$$

where J_y for y = 1994–1998, is the number of all the groups encountered in all of the surveys from 1994 to 1998, so that K_y is the same for each of the surveys in those years. For y = 1999 and 2000, J_y was the number of groups from the years 1997 to 2000, so that K_y was changed after 1998.

Abundance Estimate

The three sections of Cook Inlet (Fig. 1) were each surveyed different numbers of times each year, so it is necessary to estimate abundance in each section separately as,

$$\hat{N}_{s,y} = \frac{\hat{K}_y}{J_{s,y}}\sum_{j=1}^{J_{s,y}}\sum_{i=1}^{G_{j,s,y}}\hat{n}_{i,j}$$

$$Var(\hat{N}_{s,y}) = \frac{1}{J_{s,y}-1}\sum_{j=1}^{J_{s,y}}\left(\hat{N}_{s,y} - \hat{K}_y\sum_{i=1}^{G_{j,s,y}}\hat{n}_{i,j}\right)^2 + \frac{\hat{K}_y^2}{J_{s,y}^2}\sum_{j=1}^{J_{s,y}}\sum_{i=1}^{G_{j,s,y}}Var(\hat{n}_{i,j}) + CV^2(\hat{K}_y)\hat{N}_{s,y}^2,$$

where $\hat{N}_{s,y}$ is the estimated average abundance in section s during year y,
$G_{j,s,y}$ is the number of groups seen in section s during survey j in year y,
$J_{s,y}$ is the number of surveys conducted in section s during year y, and
$\hat{n}_{i,j}$ is the estimated number of whales in group i of survey j.

The abundance estimate for the entire inlet each year is then the sum of the abundance estimates for the three sections:

$$\hat{N}_y = \sum_{s=1}^{3}\hat{N}_{s,y},$$

$$Var(\hat{N}_y) = \sum_{s=1}^{3}Var(\hat{N}_{s,y}),$$

where $\hat{N}_y$ is the estimated average abundance in year y.

Trend in Abundance and Probability of Depletion

To test for a trend in abundance during the years when large numbers of beluga were harvested, 1994–1998 (Mahoney and Shelden, 2000), and estimate the probability that the population was depleted by 1998 (i.e. 50% of the 1994 level), a population model was fitted to the abundance estimates for those years and projected forward to 1999. The model was based on the assumptions that: 1) the per capita natural rate of increase of belugas remains constant from year to year, 2) most of the hunting-related mortality occurs in June and July and impacts males and females equally, 3) population growth occurs in the spring before the census, and 4) immigration and emigration do not occur (O'Corry-Crowe et al., 1997; Laidre et al., 2000).

Annual change in the population was then modeled as,

$$N_{y+1} = (N_y - H_y)(1+r),$$

where N_y is the abundance in year y,
H_y is the total harvest-related mortality in year y, and
r is the net per capita annual increase in the population (i.e. the difference between the birth rate and the natural mortality rate).

Two possible models were considered for annual harvest mortality: 1) harvest remained constant from year to year ($H_y = H$), and 2) harvest was a con-

Table 1.—Beluga groups reported during surveys of Cook Inlet, Alaska, 1994–2000, used to estimate abundance and/or corrections for missed groups. Groups summed for the abundance estimates are indicated in the survey and section columns. "Survey" indicates which survey within the year in which the sighting occurred and "Section" refers the section of the inlet, northwest, northeast, and south (Fig. 1) in which the sighting was located. "Estimation method" indicates whether group size was estimated from video analysis (vid.) or by correction of counts from aerial observers (obs.). "Group size" is the corrected estimate for the respective group (from Hobbs et al., 2000). The last three columns indicate sighting records used in the logistic regression to estimate the probability that a beluga group might have been missed by the aerial observers.

Date	Group	Survey	Section (Fig. 1)	Sighting location	Estimation method	Group size ($\hat{n}_g$)	CV($\hat{n}_g$)	Obs.[1]	Vis[2]	Seen[3]
6/2/94	1	1	NW	W. of Big Susitna R.	Obs.	394	0.60	3,2	G	1,1
	2	1	NE	Turnagain Arm	Obs.	18	0.47	3,2	G	0,1
	2	1	NE	Turnagain Arm	Obs.	18	0.47	3,2	G	1,1
	3	1	NE	Chickaloon Bay	Obs.	47	0.43	3,2	F	1,0
6/3/94	1			Pt. Possession	Obs.	27	0.39	4,3	G	0,1
	2	1	S	Kachemak Bay	Obs.	8	0.31	4,3	E	0,1
	3	1	S	Kachemak Bay	Obs.	13	0.29			
6/4/94	1	1	S	Iniskin Bay	Obs.	4	0.30			
	2	2	NW	W. of Big Susitna R.	Obs.	144	0.31	3,1	G	0,1
	3	2	NW	Big Susitna R.	Vid.	252	0.22	3,1	G	1,1
	4	2	NW	W. of Little Susitna R.	Vid.	475	0.24	3,1	G	1,1
6/5/94	1	3	NE	Pt. Possession/E. Foreland	Obs.	2	0.93	2,3	F	0,1
	2	3	NW	Beluga R.	Vid.	41	0.51	2,3	G	1,0
	3	3	NW	W. of Big Susitna R.	Vid.	20	0.96	4,1	G	0,1
	4	3	NW	W. of Big Susitna R.	Obs.	21	0.34	4,1	G	0,1
	5	3	NW	W. of Big Susitna R.	Vid.	55	0.51	4,1	G	1,1
	6	3	NW	Little Susitna R.	Obs.	337	0.19	4,1	G	1,1
	7	3	NE	Chickaloon Bay	Vid.	11	1.10	3,2	G	1,1
7/18/95	1	1	NE	Chickaloon Bay	Vid.	29	0.36	4,1	G	0,1
	2	1	NW	McArthur R.	Obs.	1	1.15			
	3	1	NW	Big Susitna R.	Obs.	731	0.36	1,3	G	1,1
7/19/95	1	2	NE	Chickaloon Bay	Vid.	20	0.41	5,4	G	1,1
	2	2	NW	McArthur R.	Obs.	8	0.58			
	3	2	NW	Shirleyville	Obs.	4	0.42			
	4	2	NW	Big Susitna R.	Vid.	348	0.22	4,5	E	1,1
7/20/95	1			Chickaloon Bay	Vid.	16	0.40	1,5	E	1,1
	2+3	3	NW	Big Susitna R.	Vid.	73	0.50	1,5	E	1,1
7/21/95	1	4	NW	Big Susitna R. (E)	Vid.	32	0.65	3,2	G	1,0
	2	4	NW	Big Susitna R. (W)	Obs.	278	0.77	3,2	G	1,0
	3	4	NW	Knik Arm	Obs.	2	0.42			
	4	4	NE	Chickaloon Bay	Obs.	43	0.26	5,3	G	1,1
7/22/95	1	1	S	Big R.	Vid.	17	0.42			
7/24/95	1			Drift R.	Obs.	5	1.05	3,4	F	1,0
	2	4	NW	McArthur R.	Obs.	4	0.68	1,5	P	0,1
	3	4	NW	Big Susitna R. (W)	Vid.	272	0.27	1,5	G	1,1
	4	4	NW	Big Susitna R. (E)	Obs.	94	0.45			
6/11/96	2			Lewis R.	Obs.	13	0.69	1,4	G	1,0
6/12/96	4	1	NE	Pt. Possession	Obs.	48	0.58	5,6	F	1,0
	1			Theodore R.	Obs.	12	0.39	6,4	G	1,1
	2			Lewis R.	Vid.	33	0.60	6,4	G	1,1
	3			Big Susitna R.	Vid.	199	0.19	6,4	F	1,1
6/13/96	1	1	NW	Knik Arm	Obs.	17	0.26	5,4	E	1,1
	2	1	NW	Knik Arm	Obs.	18	0.45	5,4	E	1,1
	3	2	NE	Pt. Possession	Vid.	69	0.26			
	4	1	NW	Ivan R.	Obs.	168	0.20	6,1	G	1,1
	5	1	NW	Big Susitna R.	Vid.	229	0.17			
6/16/96	1	2	NW	Knik Arm	Obs.	37	0.15			
	2	2	NW	Knik Arm	Obs.	28	0.32			
	3	3	NE	Pt. Possession	Vid.	40	0.36	1,4	E	1,1
	4	2	NW	Lewis/Ivan R.	Vid.	365	0.09	6,5	G	1,1
	5	2	NW	Big Susitna R.	Vid.	69	0.23	4,1	E	1,1
	6	2	NW	Big/ Little Susitna R.	Obs.	132	0.39	5,6	E	1,1
	7	2	NW	Little Susitna R.	Vid.	22	0.74			
6/8/97	1	1	NW	Knik Arm	Vid.	30	0.34			
	2	1	NW	Knik Arm	Vid.	63	0.23	5,6	G	1,1
	3	1	NW	Knik Arm	Vid.	76	0.20	1,7	E	1,1
	4	1	NW	Knik Arm	Obs.	2	0.42			
	5+6	1	NW	Knik Arm	Vid.	56	0.17			
	7	1	NW	Knik Arm	Obs.	4	0.42			
	8	1	NE	Chickaloon Bay	Vid.	20	0.32	6,5	G	0,1
	9	1	NE	Chickaloon Bay	Vid.	19	0.43	6,5	G	1,1
	10	1	NW	Big Susitna R.	Vid.	127	0.21	7,1	G	1,1
6/9/97	1	1	S	Tuxedni Bay	Obs.	2	0.42			
	2	2	NW	Big Susitna R.	Obs.	103	0.36	7,5	P	0,1

Continued on facing page.

Table 1.—Continued.

Date	Group	Survey	Section (Fig. 1)	Sighting location	Estimation method	Group size ($\hat{n}_g$)	CV($\hat{n}_g$)	Obs.[1]	Vis[2]	Seen[3]
6/10/97	1	3	NE	Chickaloon Bay	Vid.	113	0.16	5,1	P	0,1
	2	3	NW	Big Susitna R.	Obs.	140	0.35	6,7	G	1,1
	3	3	NW	Knik Arm	Vid.	153	0.12			
	4	3	NW	Knik Arm	Vid.	60	0.21			
	5	3	NW	Knik Arm	Obs.	2	0.42			
	6	3	NW	Knik Arm	Obs.	9	0.42			
6/10/98	1	1	NW	Fire I.	Obs.	21	0.52			
	2	1	NE	Chickaloon Bay	Vid.	27	0.33	4,7	G	1,1
	3	1	NW	Susitna R.	Vid.	139	0.23	5,8	F	1,0
	4	1	NW	Knik Arm	Obs.	4	0.42			
	5	1	NW	Knik Arm	Obs.	21	0.39			
	6	1	NW	Knik Arm	Obs.	7	0.48			
	7	1	NW	Knik Arm	Obs.	8	0.41	7,4	G	1,1
	8	1	NW	Knik Arm	Obs.	64	0.42	8,5	F	1,1
	9	1	NW	Knik Arm	Obs.	9	0.50			
	10	1	NW	Knik Arm	Obs.	49	0.33			
6/12/98	1	2	NW	Little Susitna R.	Vid.	53	0.28			
	2	2	NW	Knik Arm	Obs.	9	0.89	8,5	G	0,1
	3	2	NW	Knik Arm	Vid.	26	0.46			
	4	2	NW	Knik Arm	Vid.	18	0.53			
	5	2	NW	Knik Arm	Vid.	21	0.37	4,8	G	0,1
	6	2	NW	Knik Arm	Obs.	19	0.66			
	7	2	NW	Knik Arm	Vid.	45	0.51			
	8	2	NE	Chickaloon Bay	Vid.	31	0.40	4,8	F	1,1
	9	2	NE	Chickaloon Bay	Vid.	19	0.68	4,8	F	1,1
6/15/98	1	3	NE	Chickaloon Bay	Vid.	89	0.22	4,8	G	1,1
	2	3	NW	Little Susitna R.	Obs.	2	0.42			
	3	3	NW	Little Susitna R.	Vid.	285	0.14	5,1	E	1,0
	4	3	NW	Knik Arm	Obs.	21	0.42			
	5	3	NW	Knik Arm	Vid.	40	0.21	8,4	G	1,1
	6	3	NW	Knik Arm	Vid.	4	1.08			
	7	3	NW	Knik Arm	Vid.	11	0.66			
6/9/99	1	1	NW	Little Susitna R.	Vid.	314	0.17	5,8	E	1,1
	2	1	NW	Knik Arm	Obs.	54	0.11			
	3	1	NE	Chickaloon Bay	Vid.	29	0.46			
6/11/99	1			Little Susitna R.	Vid.	244	0.41	1,5;8,4	F,P	1,1;1,1
6/12/99	1	2	NE	Chickaloon Bay	Vid.	2	0.44	8,1	E	1,1
	2	2	NE	Chickaloon Bay	Vid.	30	0.19			
	4	2	NW	Beluga R.	Vid.	12	0.52	4,5	E	0,1
	5	2	NW	Big Susitna R.	Vid.	92	0.21	4,5	E	0,1
	6	2	NW	Little Susitna R.	Vid.	178	0.41	1,8	E	1,1
	7	2	NW	Knik Arm	Vid.	38	0.26	5,4	E	1,1
6/13/99	1	3	NW	Big Susitna R.	Vid.	25	0.33	8,4	G	0,1
	2	3	NW	Little Susitna R.	Vid.	258	0.21	8,4	E	1,1
	4	3	NW	Knik Arm	Vid.	17	0.23			
6/7/00	1			Knik Arm	Vid.	44	0.27	1,8	E	1,0
6/8/00	1	1	NW	Little Susitna R.	Vid.	317	0.14	1,4	E	1,1
	2	1	NW	Little Susitna R.	Vid.	33	0.23			
	3	1	NE	Chickaloon Bay	Vid.	11	0.34	4,1	E	1,1
6/11/00	1			Little Susitna R.	Vid.	231	0.12	5,1	E	1,1
	2			Beluga R.	Vid.	2	0.39	4,8	E	1,0
6/12/00	1	2	NE	Chickaloon Bay	Vid.	31	0.18			
	2	2	NE	Chickaloon Bay	Vid.	11	0.23			
	3	2	NW	Little Susitna R.	Vid.	357	0.12	5,4	E	1,1
	4	2	NW	Little Susitna R.	Vid.	27	0.41			
	5	2	NW	Knik Arm	Obs.	13	0.79	5,4	G	1,1
	6	2	NW	Knik Arm	Vid.	3	0.70	5,4	G	1,1
	7	2	NW	Knik Arm	Vid.	49	0.18			
6/13/00	1			Chickaloon Bay	Obs.	9	0.51	1,4	G	1,1
	2			Big Susitna R.	Vid.	156	0.16	1,4	E	1,1
	3			Knik Arm	Obs.	18	0.32	5,8	E	1,1
	4			Knik Arm	Obs.	9	0.68	5,8	E	1,1
	5			Knik Arm	Vid.	28	0.20			

[1] Observer code identifications for the 8 primary Observers; the ordered pairs indicate whether the respective Observers were in the left front or left middle positions; the left rear seat was used by visitors and so is not included here.

[2] Visibility conditions reported by Observers (E, G, F, P) are excellent, good, fair, and poor, respectively.

[3] Sighted (1) or missed (0) groups are indicated in ordered pairs as in the "Obs." column.

stant fraction of the population ($H_y = h N_y$). The likelihood of a particular set of parameter values $L[N_{1994}, (H \text{ or } h), r]$ was estimated as,

$$L[N_{1994}, (H \text{ or } h) r] = \prod_{y=1994}^{1998} \frac{1}{N_y}$$

$$Norm\left[\ln(\hat{N}_y), \begin{cases} \ln(N_y), y = \\ 1994,\ 1996-1998 \\ \ln(N_y - H) \text{ or} \\ \ln\left(N_y(1-h)\right), y = 1995 \end{cases}, \ln\left(1 + CV^2(\hat{N}_y)\right)^{\frac{1}{2}}\right],$$

where $Norm(x, \mu, \sigma)$ is the probability density at x from the normal distribution with mean μ and standard deviation σ. The harvest model with the larger likelihood at the best parameter fit was then chosen as the more likely. A set of 10,000 simulations of the chosen model were run using parameter values drawn from prior distributions, following a Monte Carlo integration approach (Press, 1989) to approximate prior and posterior distributions on depletion level (D_y). This was defined as:

$$D_y = \frac{N_y}{N_{1994}}$$

using the selected harvest model.

The model requires three parameters (N_{1994}, either H or h, and r) and distributions for those parameters. The initial population size, N_{1994}, was drawn from the lognormal distribution used to estimate the confidence interval for the abundance estimate. The harvest, H, was drawn from a uniform distribution between 50 and 150 whales, and the harvest rate, h, was drawn from a uniform distribution between 5% and 40% of the population per year. The per capita growth rate, r, was chosen from a uniform distribution of –10% to +10% per capita increase. Negative growth rate was included in the prior distribution to allow for the possibility that habitat factors other than hunting were driving the population down. The results from the simulation runs were grouped into 10% bins by D_y. To create a probability distribution for D_y, the likelihoods were averaged in each bin, and the averages were scaled so that the sum of the averages over all bins equaled 1.

Results

There was a total of 144 sightings of groups of belugas made during aerial surveys of Cook Inlet in 1994–2000. Of these, 112 were used to estimate abundance for the respective years (Table 1). Many of these are resightings of groups encountered on different survey days and years. Of the 112 groups, abundances for 65 were estimated from video and 47 from observer counts (Table 1). Hobbs et al. (2000) provide abundance estimates for each of these sightings, including corrections for availability and detection biases.

A total of 81 whale groups (Table 1) were reported while pairs of observers were searching independently (the search effort was not considered independent if there was open verbal communication, e.g. during weather checks or additional sightings made while a group was being circled). Logistic regression indicated the best model fit using the following covariates: 1) the natural logarithm of group size, 2) observers clumped into three sighting-performance categories, and 3) visibility recoded as a numeric variable (Table 2). The correction for whales in missed groups was 1.015 (CV = 3%) for the years 1994–98 and 1.021 (CV = 1%) for the years 1999 and 2000.

Abundances were calculated for each geographical section within Cook Inlet (Fig.1) and totaled for each year 1994–2000 (Table 3, Fig. 2). Calculated abundances were 653 (CV = 0.43) in 1994, 491 (CV = 0.44) in 1995, 594 (CV = 0.28) in 1996, 440 (CV = 0.14) in 1997, 347 (CV = 0.29) in 1998, 367 (CV = 0.14) in 1999, 435 (CV = 0.23, 95% CI = 279–679) in 2000. For management purposes the current N_{best} = 435 and N_{min} = 360 (Wade and Angliss, 1997).

Of the two models considered for the Bayesian analysis, the best fit occurred in the model with a constant annual harvest (likelihood = 1.70 E-13, H = 135, N_{1994} = 706 and r = 0.10, D_{1998} = 0.49, D_{1999} = 0.32). The best fit for the model with a proportional harvest was slightly less likely (likelihood = 1.54 E-13, h = 0.22, N_{1994} = 748 and r = 0.07, D_{1998} = 0.49, D_{1999} = 0.41). Applying the Bayesian analysis to the constant harvest model indicates that—although the most likely depletion level at the time of the survey in 1998 was below 50%—the probability that the population was depleted at that time (i.e. probability that $N_{1998}/N_{1994} = D_{1998} < 50\%$) was 0.47 (Table 4, Fig. 3). Projecting the model forward 1 year to June 1999 shows the most likely depletion level was between 0.3 and 0.4, and the probability that $D_{1999} < 50\%$ was 0.72 (Table 4). Note that this analysis only considers depletion during the period 1994–98. If the population was significantly less than carrying capacity in 1994 when these abundance estimates began, then

Table 2.—Coefficients of the logistic regression to estimate the probability that a group of belugas was seen by an observer while doing aerial surveys in Cook Inlet. Observers were clumped into three groups based on performance: A, B, or C. Group A was the index group. Each visibility was given a numeric value (Excellent = 0, Good = 1, Fair = 2, Poor = 3) and treated as a linear variable rather than a categorical variable. The best model was chosen by comparing the AIC.

Coefficients	Value	SE	t value
1994–1998			
Intercept	2.37	1.24	1.91
Ln(group size)	0.34	0.21	1.65
Observer group B	–1.26	0.78	–1.63
Observer group C	–2.02	0.80	–2.54
Visibility Number	–1.03	0.37	–2.77
1999–2000			
Intercept	–0.56	0.72	–0.78
Ln(group size)	0.53	0.21	2.49

Table 3.—Estimated abundance of belugas by year and section in Cook Inlet.

Year	Northwest	CV	Northeast	CV	South	CV	Total	CV
1994	580	47%	48	108%	25	19%	653	43%
1995	444	48%	31	43%	17	43%	491	44%
1996	542	30%	52	37%	0		594	28%
1997	362	9%	76	69%	2	43%	440	14%
1998	292	32%	55	60%	0		347	29%
1999	336	15%	31	25%	0		367	14%
2000	408	23%	27	82%	0		435	23%

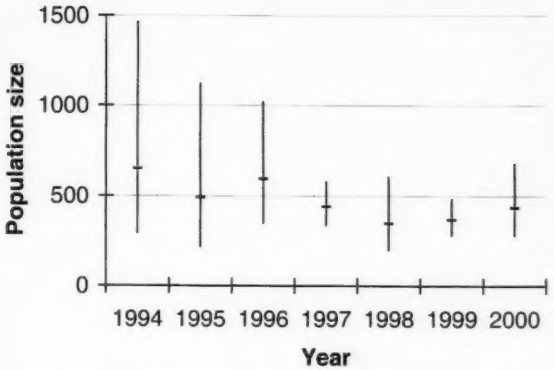

Figure 2.—Estimated abundance of Cook Inlet belugas for the years 1994 through 2000. Marks indicate point estimates, and vertical bars indicate the 95% log-normal confidence intervals.

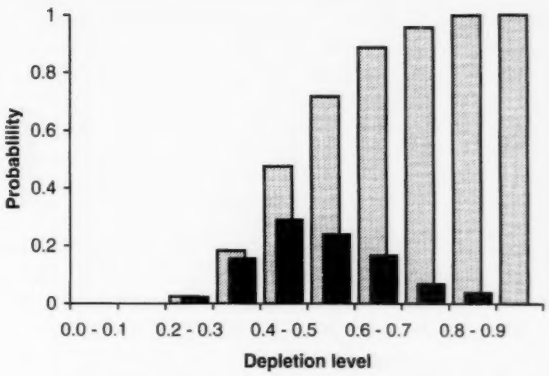

Figure 3.—Probability distribution of depletion level of the 1998 abundance below the 1994 population size (N_{1998}/N_{1994}). Dark columns are the probability that the depletion level falls into the indicated range. Light columns are the cumulative distribution and indicate the probability that the depletion level is in the indicated range or lower.

the depletion would be greater. The Native take of belugas in Cook Inlet ceased in 1999 (Mahoney and Shelden, 2000), and there has been no evident decline in abundance since that time (Fig. 2); however, there are too few years since then to reliably quantify a new trend in abundance.

Table 4.—Probability distribution from Monte Carlo simulations of depletion level at the time of the June 1998 survey counts and projected to the June 1999 survey assuming that hunting continued at the same level.

Depletion level	1998 probability	Cumulative probability	1999 probability	Cumulative probability
0.0 to 0.1	0.000	0.000	0.001	0.001
0.1 to 0.2	0.000	0.000	0.080	0.081
0.2 to 0.3	0.025	0.025	0.199	0.280
0.3 to 0.4	0.158	0.183	0.256	0.535
0.4 to 0.5	0.292	0.475	0.189	0.725
0.5 to 0.6	0.241	0.716	0.141	0.866
0.6 to 0.7	0.169	0.885	0.076	0.942
0.7 to 0.8	0.071	0.955	0.039	0.980
0.8 to 0.9	0.041	0.997	0.018	0.998
0.9 to 1.0	0.003	1.000	0.002	1.000

Discussion

The rigor and intensity of the protocol applied in the surveys reported here make the surveys highly comparable among years (1994–2000) but not necessarily comparable to surveys conducted by other researchers prior to the 1990's (reviewed in Rugh et al., 2000). Although earlier surveys in Cook Inlet often resulted in beluga counts of about 300–400, these surveys used different protocols and may not have even been focused on belugas. Therefore, it is inappropriate to attempt abundance trend analyses based on counts from 10- to 30-yr-old studies with very little supporting documentation.

The abundance estimates presented here are very sensitive to statistics on the typical surfacing interval of a beluga. The surfacing interval information was based on data from 5 belugas in Cook Inlet, each tagged separately and tracked for only a few hours (Lerczak et al., 2000). Individuals showed a wide range of dive intervals, and very little information is available on the degree of correlation in dive behavior within large groups. If all whales in a group dove in complete synchrony, or if each of the whales in a group dove at truly random intervals, estimates of the number of sub-surface whales would be relatively straightforward. But the reality is that dive behavior may be correlated between individuals engaged in the same activities, and it may be correlated over extended periods for the same individual. This correlation contributes to the wide ranges in counts from one aerial pass to the next even when other variables (observer, visibility, etc.) have not changed. Clearly what is needed to decrease the variance on this important parameter is a larger sample size of tagged whales and a better understanding of the relationship between dive intervals and behaviors that can be identified from the air.

A significant portion of the variability in the annual abundance estimates is the result of variation among survey days. This variation is greater than can be explained by the variances for those days. Thus, we must conclude that there remain some sources of variability that have not been accounted for. The most likely candidate is variability resulting from the correlated dive behavior discussed above. We assumed that each whale was choosing dive intervals at random from its own dive interval distribution, when in fact these choices may be correlated among individuals in a group. If this is the case, then the variances of the group size estimates and the daily abundance estimates may have been underestimated.

The high density of beluga aggregations has made them easy to find and convenient to work with in the video recordings. This density also made them difficult to count while passing by them

in an aircraft. This difficulty might result in an underestimation of a trend in abundance if observers tend to undercount more at high densities than at low densities; as group sizes decline from year to year, undercounting would diminish, and observers' counts would become more accurate. Hobbs et al. (2000) provide exacting corrections to account for this form of detection bias in observer counts, such that this concern is minimized in the final abundance estimates.

Although our field methods and analyses were designed to satisfy the three criteria listed in our introduction, several field seasons were required to accumulate the necessary data and auxilliary experimental results to utilize the methods described above and in Hobbs et al. (2000). To accomodate the need for a timely preliminary abundance estimate, an ad hoc approach was developed from the 1994 survey data, resulting in an estimate of 749 whales (Hobbs et al.[1]). This preliminary estimate for 1994 has been replaced by the more accurate estimate of 653 whales. Also, a preliminary estimate of 357 whales from the 1999 survey data is replaced here by the final estimate of 367.

In 1999 a digital camera system was introduced to collect the counting video recordings (Hobbs et al., 2000). The experiments necessary to develop a correction for whales at the surface that were missed by the video did not have sufficient sample sizes until the completion of the 2000 survey. Thus a preliminary abundance estimate was developed using video only for groups where it was certain that no whales were missed and relying on observer counts for the remainder of the group size estimates. With the completion of the necessary video experiments in 2000, these group size estimates were revised, and the abundance estimate was recalculated.

[1] Hobbs, R. C., J. M. Waite, D. J. Rugh, and J. A. Lerczak. 1995. Abundance of beluga whales in Cook Inlet based on NOAA's June 1994 aerial survey and tagging experiments. Pap. SC/47/SM11 submitted to the Sci. Comm. of the Int. Whal. Comm. (unpubl.), 14 p. Also submitted as Annu. Rep. for Mar. Mammal Assessment Program, Off. Protect. Resour. (F/PR) NMFS, NOAA. Also circulated as Appendix V in Proc. Alaska Beluga Whale Committee; First Conf. on Biology of Beluga Whales, April 5–7, 1995, Anchorage, Alaska.

Apparently, only a few whales (1.5%) were in groups missed during these aerial surveys of Cook Inlet, based on results from the paired-observer effort. Single observers would have missed more whales (about 12%). This paired, independent observer technique suffers one underlying assumption: that we are able to account for the factors resulting in heterogeneity within the sampling. In these surveys, both of the paired observers had equal sighting opportunities. Evident heterogeneity resulted from group size, observer performance, and visibility conditions; the most important factor was group size.

When approaching single whales or small groups, sighting opportunities were limited to very few surfacings and changed significantly with time, but large groups provided nearly continuous sighting cues at a fairly constant rate. Observer performance was roughly correlated with experience such that inexperienced observers were more likely to miss groups, but after the experience of a few survey days, each observer's sighting rate approached an individual average. The impact of declining visibility conditions is evident (DeMaster et al., 2001) and supports the survey design decision to avoid surveying or excluding results when visibility was reduced.

One other source of potential heterogeneity is the distance of groups from the trackline. We did not use distance as a covariate in this analysis and consequently have assumed that detection does not decline significantly with distance. Because the trackline during coastal surveys was only 1.4 km offshore and virtually all beluga groups occurred between the trackline and shore, very few whale groups would have been missed as a function of distance alone.

Although river mouths or narrow inlets temporarily widened the effective search area, the survey also included flights up most rivers and through bays as far as was reasonable. Other than these minor irregularities, the search area was fairly constantly 1.4 km wide, and because whales were sometimes visible out to 6 km (Rugh et al., 2000), there is no evidence that distance across the transect sector was a critical factor in missing whale groups.

There have been many attempts to find appropriate correction factors for whales missed during aerial counts of belugas. Estimates have ranged from 1.15 to 2.75 (reviewed in Hobbs et al. 2000), but they do not necessarily account for all critical factors, and most are not applicable to the situation in Cook Inlet where the water is nearly opaque. The precision and multiple repetitions used in the current survey design in Cook Inlet, along with the video analysis and time-at-surface ratios recorded within the inlet, have allowed this study to produce abundance estimates with relatively high accuracy.

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Beluga, *Delphinapterus leucas*, Group Sizes in Cook Inlet, Alaska, Based on Observer Counts and Aerial Video

RODERICK C. HOBBS, JANICE M. WAITE, and DAVID J. RUGH

Introduction

It is extremely difficult to get accurate counts of large groups of cetaceans from aerial surveys, even though aircraft are usually better observation platforms than vessels or shore-based sites. To overcome this problem, methods and analyses for using video records were developed to obtain counts and estimate group sizes to correct observers' aerial counts. These methods were applied to a study of beluga whales, *Delphinapterus leucas*, in Cook Inlet that involved annual aerial surveys conducted by NOAA's National Marine Fisheries Service (NMFS) from 1994 to 2000 (Rugh et al., 2000).

The status of the Cook Inlet stock has been of special concern because of its small size (Hobbs et al., 2000), isolation (Laidre et al., 2000), and annual hunting pressures by Native Alaskans (Mahoney and Shelden, 2000). Studies of abundance of this stock and related parameters for correcting aerial counts and assessing variance have been conducted by NMFS annually since 1993.

During late spring and early summer, large aggregations of beluga whales are found near river mouths of upper Cook Inlet (Rugh et al., 2000). In recent years, very few whales have been observed anywhere other than in these nearshore areas, and most of the observed whales were within dense concentrations. Consequently, the accuracy of an abundance estimate for this population depends on accurate estimates of the sizes of these few large groups.

Since 1994, a consistent method has been used by the NMFS for counting groups of beluga whales during annual aerial surveys of Cook Inlet. This method adapted available survey designs (flying consistently at an altitude of 244 m (800 ft) and 185 km/h (100 knots) along coastal tracklines or straight offshore tracklines) to make systematic, thorough searches for whale groups (Rugh et al., 2000). Paired, independent observers provided sighting information used in an analysis of the likelihood that a group of whales was not seen (Hobbs et al., 2000). When a group was found, repeated counts were made using an extended racetrack flight pattern, such that observers always counted on one side of the aircraft while passing a group on a straight line. During each pass, two observers counted the group independently, and a third recorded the group on videotape. The timing of the start and stop of each count was recorded precisely along with the apparent quality of the counts—whether or not the whole group was in view or visibility interfered with the count.

These counting methods worked well for obtaining counts for each group and for comparing the performance of different observers. However, counts made during each pass varied widely among observers, and counts by each observer varied for successive counts of the same group, even when visibility did not change. Large, dense groups remained especially difficult to count accurately despite the standardized approach. Observers responded differently to increases

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ABSTRACT—Beluga, Delphinapterus leucas, *groups were videotaped concurrent to observer counts during annual NMFS aerial surveys of Cook Inlet, Alaska, from 1994 to 2000. The videotapes provided permanent records of whale groups that could be examined and compared to group size estimates made by aerial observers. Examination of the video recordings resulted in 275 counts of 79 whale groups. The McLaren formula was used to account for whales missed while they were underwater (average correction factor 2.03; SD=0.64). A correction for whales missed due to video resolution was developed by using a second, paired video camera that magnified images relative to the standard video. This analysis showed that some whales were missed either because their image size fell below the resolution of the standard video recording or because two whales surfaced so close to each other that their images appeared to be one large whale. The correction method that resulted depended on knowing the average whale image size in the videotapes. Image sizes were measured for 2,775 whales from 275 different passes over whale groups. Corrected group sizes were calculated as the product of the original count from video, the correction factor for whales missed underwater, and the correction factor for whales missed due to video resolution (averaged 1.17 ; SD=0.06). A regression formula was developed to estimate group sizes from aerial observer counts; independent variables were the aerial counts and an interaction term relative to encounter rate (whales per second during the counting of a group), which were regressed against the respective group sizes as calculated from the videotapes. Significant effects of encounter rate, either positive or negative, were found for several observers. This formula was used to estimate group size when video was not available. The estimated group sizes were used in the annual abundance estimates.*

in beluga density, with some observers continuing to count individual whales but narrowing their field of view, while other observers switched to counting in 10's or 20's, maintaining a larger field of view but reducing the accuracy of their counts. In addition, animals were missed due to visibility biases (availability and perception biases) (Marsh and Sinclair, 1989), which were not easily measured.

Availability bias occurs when whales are not visible to observers because the whales are completely below the surface —especially in turbid water—and so are not "available" to be counted (Marsh and Sinclair, 1989). In upper Cook Inlet, the waters are extremely turbid to the point of being nearly opaque. Secchi disk depth readings range from 1 cm to 37 cm with an average of 14 cm in areas where beluga whales are typically found (Shelden and Angliss[1]), such that any part of a beluga that is below the surface is out of sight.

Water disturbance patterns created when whales swim near the surface are often visible and can serve as sighting cues; however, observers were asked to count only those belugas that they actually saw at the surface. It is unknown to what extent their counts are influenced by the water disturbance cues. Researchers have corrected for availability bias using the formula of McLaren (1961) which uses dive interval information to estimate the inverse of the probability that a typical animal will be at the surface during the period of observation (Frost et al., 1985; Barlow et al., 1988; Laake et al., 1997). The McLaren formula also requires knowing the time that an observer spends counting whales in each patch of water which, as noted above, can vary by observer and group size.

Perception bias occurs when whales are on the surface of the water (available to be seen) but are not detected by an observer due to various possibilities, including adverse conditions (such as glare or rough seas), camouflage coloration, or observer fatigue or inexperience (Marsh and Sinclair, 1989). Perception bias is further compounded for beluga whales due to their age-specific coloration. Belugas are dark gray when born and gradually lighten as they get older, until they become completely white as adults (9–11 years) (Sergeant, 1973). When at the surface, belugas appear as white or gray ovals against a dark background of water. The white adult whales strongly contrast with the water, which makes them easy to see even at a distance. The smaller, darker whales are more likely missed in aerial counts.

To circumvent these inherent problems with observers' counts from an aircraft, a method using video recordings was developed as an alternative. Video recordings have precise timing, have a well defined field of view, and can be examined closely frame-by-frame to ensure that all of the recorded beluga images are counted. These properties allowed for precise, repeatable counts, and accurate measurements of the time available for counting, including the time that whales were at the surface. The objectives of the video recordings during these surveys and subsequent analysis were to collect the following types of data:

1) Accurate counts of all visible surfacings in a group over a measured period of time.
2) Accurate measurement of the time whales were visible at the surface (start to end of a surfacing).
3) Apparent size of whale images in the video recordings.
4) Gray-scale classification for whale images in video recordings.
5) And, matching of whale images between simultaneous video recordings at two different magnifications.

Using these data and the average dive interval from a radio-tagging study (Lerczak et al., 2000), the counts of surfacing whales from the video could be corrected for availability bias and perception bias. Availability bias could be estimated using the McLaren (1961) formula, and perception bias could be estimated by matching images between simultaneous high and low magnification video recordings of the same group. The calculations of group size resulting from the video analysis could then be used to develop a correction method for the observer counts independent of assumptions about observer behavior and counting techniques.

Methods

Aerial Counts of Beluga Groups

Aerial counts were made by pairs of observers tallying beluga whale sightings independently during counting passes (Rugh et al., 2000). A racetrack flight pattern, typically 2–4 km from end-to-end and 1–2 km across, depending on the size of a group, usually allowed two counting passes per circuit around the group, if glare was not a problem (Fig. 1). Start and stop times were precisely noted for each counting pass, and observers graded the conditions during each count (from A to D for excellent to poor). The protocol was to continue this process until each of the observers had made at least four counts under acceptable conditions (A or B). Then observers traded positions, and the process was repeated.

Typically, then, each group of whales was counted 16 times (4 times by 4 different observers). This method allowed for repeatable, independent counts by four observers with essentially the same presentation of the group and a measure of time spent counting. The number of counts was reduced when groups were small (<5 whales) or dense air traffic prevented staying in the area. Each observer recorded counts independently, and counts were not discussed among observers during the remainder of the project. To further maintain independence, the counts were entered into the database by a colleague who did not participate in the counts, or they were entered only after the survey was completed.

Standardized Counting Video

Videotape recordings (hereafter referred to as counting video), concurrent to observers' counts of beluga whale

[1] Shelden, K. E. W., and R. P. Angliss. 1995. Characterization of beluga whale (*Delphinapterus leucas*) habitat through oceanographic sampling of the Susitna River delta in Cook Inlet, Alaska, 11–18 June 1994. *In* D. P. DeMaster, H. W. Braham, and P. S. Hill (Editors), Marine Mammal Assessment Program status of stocks and impacts of incidental take, 1994, p. 77–90. Annu. Rep. submitted to Off. Protect. Resour., Natl. Mar. Fish. Serv., NOAA, 1335 East-West Highway, Silver Spring, MD 20910.

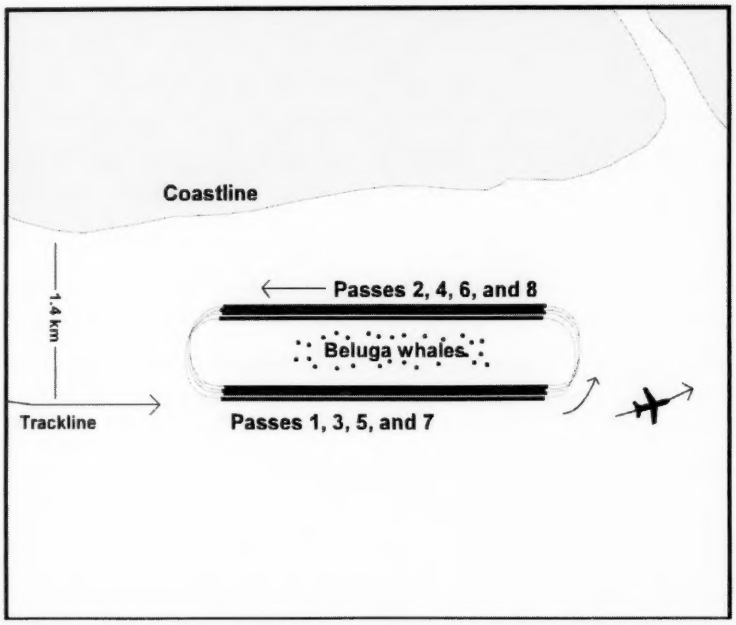

Figure 1.—Schematic of the racetrack flight pattern used to count beluga whale groups in Cook Inlet. After observers saw a group of whales, the aircraft circled in a series of straight-line passes such that each pair of observers had four opportunities to count the group from the same side of the aircraft. The group was videotaped concurrent to each counting pass.

groups, were collected with a Canon[2] Hi-8 814 XL-S video camera during 1994–98 and a Sony Digital 8 DCR-TRV103 video camera during 1999–2000. These tapes were used to count whales in each group independent of the observers. In the aircraft, the videographer was positioned at an open window facing the same direction as the two observers so that all three would have essentially the same view of each group of whales (Rugh et al., 2000 provides details).

Videotape, with a time-stamp, was recorded during nearly every counting pass over a beluga group. The counting video was taken in either of two ways: 1) The "point" method was used if the whole group could be seen in the viewfinder of the video camera. In this case, the camera was pointed at the group and moved to keep the entire group of whales in the field of view until they were out of sight (Fig. 2a); or 2) The "scanned" method was used when groups were too dispersed for all individuals to be in view at one time. With this method, the camera was held still and perpendicular to the trackline so that the video scanned the length of the group as the aircraft moved past (Fig. 2b).

Zoomed Video

Although the counting video was valuable for counting clearly visible, distinct whales in a group, small whales may not have been visible in the video at the limits of the resolution, or whales may not have been distinguishable due to close proximity with other whales. In 1996, a second video camera (Ricoh Hi-8 R800H) was used at a higher magnification (8×) during counting passes, to test the visibility of small and gray whales in the standard video.

Upon examination of the zoomed video, we found that the narrow field of view resulted in capturing few usable whale images during these passes. An experiment was then devised in which a large group of beluga whales was circled continuously while both cameras videotaped the group. The two video cameras (standard and zoomed) were mounted side by side on a board so they were held steady and parallel to each other. The circling allowed whales to be in view for longer periods of time and, thus, they were more likely to be captured on the zoomed video. This circling experiment was repeated in 1998 and 1999.

In June 2000, a Sony Digital Camcorder DSR-PD100A replaced the Ricoh as the zoomed video camera, and it was used during counting passes instead of a circling experiment. It had higher resolution and could be zoomed to a lower magnification (~5×) and still collect useable whale images while allowing a broader field of view. Sufficient zoomed images were captured using this camera during counting passes so that a separate experiment was not necessary.

It was assumed that within the viewing range of the zoomed video, all whales at the surface could be distinguished. We believe this assumption is reasonable, because the higher magnification allowed positive identification of small dark gray whales next to large white whales and the distinction between larger gray and white animals.

Video Analysis

Each pass on the videotapes was reviewed to evaluate its quality for counting beluga whale groups and was given a rating (excellent, good, fair, poor, or unacceptable). The highest rating was given to passes in which the camera panned smoothly while remaining in focus and the margins of a group were visible. Video passes were given a lower rating if all or a part of a group was obscured by glare, confused by waves, or if focus, magnification, or panning varied rapidly. Only excellent and good passes were used for the group size estimation analysis.

The video recordings were examined using a Panasonic high resolution monitor and a Hi-8 video cassette recorder (VCR) (Sony EVO 9500A) (1994–98)

[2] Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

or the Sony digital camera in playback mode (1999–2000) capable of advancing and reversing the tape frame-by-frame and assigning a unique time and frame count number to each frame. Each frame corresponded to 1/30th of a second.

Groups were counted in two different ways according to group size: 1) for small groups, whales were counted directly from the monitor screen as the video played at regular or slow speed and 2) for large groups, whale locations were "captured" by stopping the video every 0.5 seconds (15 frames). This timing was based on the assumption that no whale would surface and dive again within a 0.5-sec period.

Transparency sheets were placed on the monitor screen and marked with dots to indicate the position of each beluga image. The sheets were then compared by placing one on top of the next; this allowed for differentiating between new sightings and whales which were resighted from one sheet to the next. New sightings were marked as new and tallied by sheet. The number of whales on the first sheet plus the number of "new" whales on each successive sheet were then summed to derive a total count for the aerial pass.

To correct for availability bias, the time spent counting was needed. This was determined differently depending on how the video was taken. For the "point" groups, the amount of time that the group was in view was used. For the "scanned" groups, timing was based on how long an object on the water was in view across the screen.

This method of counting beluga whales from video recordings was developed in several steps. Initially, two people viewed an aerial pass together with open discussion about which images represented actual beluga whales. Then a second series of counts were made by three people independently (including the two who had made the first count together). These counts were then examined sheet-by-sheet (every 0.5-sec) by all three reviewers. Discrepancies between reviewers were discussed, and a consensus was reached on whether a dot on the screen could be considered a whale or not.

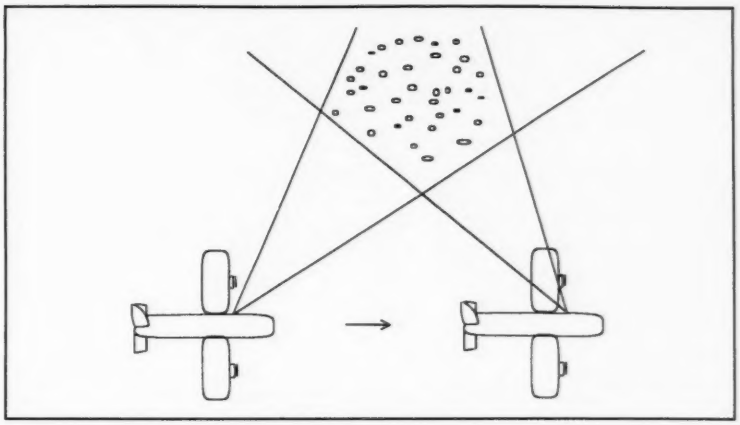

Figure 2a.—Video camera position during a counting pass. In a "point" view of a whale group, the camera is centered on the group, and the videographer changes the camera angle to keep the group centered.

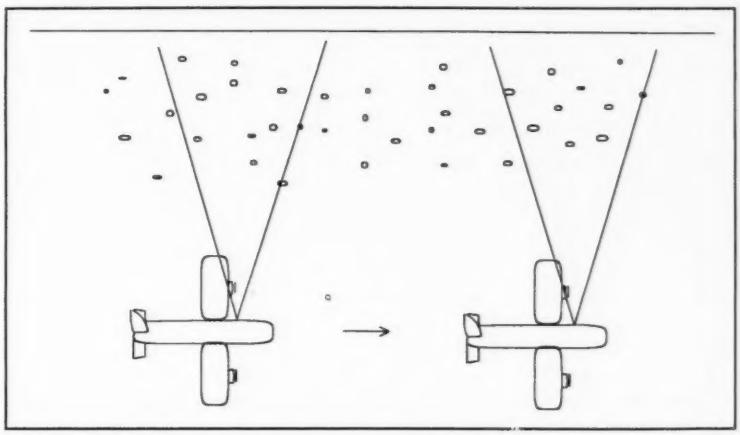

Figure 2b.—In a "scan" view, the video camera is held at a fixed angle (usually centered on the beam line), and the group is videotaped as the plane flies past.

For example, we found that a white bird in the video could be mistaken for a beluga whale, but we learned through this process how to recognize which dots were birds. After the method was developed by the initial group of three analysts, new analysts were trained by following a progression from open discussion, checks on their counts by experienced analysts, to independent analysis.

Time-at-the-surface, Image Size, and Gray-scale

To determine the distribution of whale image sizes visible from the aerial video and to estimate the time that whales were visible at the surface, a sample of whales was examined from each of the passes that were counted on transparency sheets. For each group, whales from every tenth sheet (every 5 sec) were identified with a number. Since the average dive interval is typically longer than 20 sec (Lerczak et al., 2000), this method essentially grabbed a random subsample of 10–30 whales per group. Each numbered whale was then followed using the frame-by-frame mode on the video cassette recorder; essentially following a whale from the time it

first appeared to the time it disappeared. Time and frame numbers were used to determine the length of time each whale was visible at the surface, so that the error in timing was at most 0.07 sec.

Images of whales that were measured for time-at-the-surface were also measured for image size and given a gray-scale rating. Measurements were taken at the halfway point in each whale's time-at-the-surface. A plastic metric ellipse template was used as a scale for size. The template was copied, doubled, and reduced by half (using a photocopier) to create a set of standard sizes of white ellipses on a gray background to match the typical image and range of sizes of the whale images. Each whale ellipse was classified with the length of the major axis (in millimeters) relative to the standardized scaled chart. Measurements by two independent analysts were averaged. A gray-scale rating for each whale (bright white, dull white, and gray) was determined by consensus.

Comparison of Counting Video and Zoomed Video

The zoomed video was evaluated for usable sections. Using two video players and monitors side-by-side, segments from the zoomed video were matched to segments taken from the counting video by comparing the spatial and movement patterns of whales. The two videotapes were synchronized to the nearest frame possible. Once segments were synchronized, the relative magnification was measured by finding a pair of whales on the zoomed video that could be matched on the standard video.

Positions of the whales were marked on transparencies sheets placed on the monitor screens and distances in millimeters measured between the pair of whales on each screen. Using the position of the matched whales and the relative magnification, the boundary of the zoomed image on the counting video could be calculated. A rectangle was then drawn on the standard video sheet, marking the boundaries of the zoomed image. Marks were made on the transparencies indicating whether whales were visible on both videotapes or only seen on the zoomed video.

The size of whale images in the zoomed frames were then measured following the method of the counting video (using the half-way time calculated for the counting video when it was available) and assigned a gray-scale rating following a scheme with four shades (white, off-white, light gray, and dark gray). Because the images were larger, it was possible to distinguish four gray-shades rather than the three shades used in the standard video.

Correction for Perception Bias

Detecting whales in video recordings is limited by the resolution of the video system. Probability of detection was measured by comparing the whales seen in the zoomed video to those seen in the corresponding region on the counting video. The whale images in the zoomed video were each assigned to one of three categories: 1) whales that were seen in both the zoomed and counting video, 2) whales in the zoomed video that were missed in the counting video due to proximity—two whales surfacing close to each other appear as one large image on the counting video, or 3) image size—a whale seen in the zoomed is too small or gray so that it falls below a threshold and does not form a visible image on the counting video. The two mechanisms (proximity and image size) that affect whale detection in the counting video require different approaches for correction.

Proximity Correction

When two whales were close enough together to appear as a single whale on the counting video, the space between them was much narrower than the width of an average whale. Consequently, these two images would be merged throughout the typical range of magnifications used in the counting video, regardless of their relative size. Thus, a constant ratio could be used to correct for whales missed due to proximity:

$$\frac{J_z}{J_z - J_p},$$

where J_z is the number of whales seen in the zoomed video and J_p is the number of whales missed due to proximity.

Image Size Correction

The resolution of a video system is limited by the density of scan lines in the video recording system and the density of pixels on the display monitor. This process of scanning and pixelation has the effect of smearing images and edges by averaging the gray scale and hue across each pixel. If a pixel is half water and half beluga, then it will appear to have a gray scale and hue halfway between that of the water and the beluga. A large, white beluga will appear as a bright white ellipse with a fuzzy edge that fades to the gray-scale of the water. A gray beluga will appear as a gray ellipse with a less distinct fading to the water color. Small, gray belugas or distant belugas of any hue may not have a sufficiently large image to completely fill any pixels so that the image is entirely made up of these averaged pixels.

Because the edge of the image has been blurred, it is necessary to interpret by eye the margin of the image from the surrounding background. Experience has shown that with a limited amount of training, consistent and repeatable measurements of beluga images can be made. However, the measurement method is partially subjective, so it is necessary to estimate the bias in the interpreted image size. The smearing occurs only at the edges, so the bias should be independent of size. The gradient that is interpreted is dependent on the difference in hue between the object and the background. The subjectivity involves a determination of the point along this gradient that is the edge of the image.

The lengths of the images at the mid times of beluga surfacings matched between the counting and zoomed videos can be related by the following formula:

$$\frac{L_z}{m} = \frac{l_z - b}{m} = l_c - b = L_c,$$

where L_z and L_c are the unbiased sizes of the whale images on the zoomed and counting videos, respectively; l_z and l_c are the measured sizes of the whale images on the zoomed and counting videos, respectively; m, is the relative magnifica-

tion between the zoomed and counting video frames (obtained as the ratio of the distance between centers of two whale images seen on both the counting and zoomed video); and b is the bias resulting from smearing of the edge.

An average value for the bias can be estimated from several image pairs as,

$$\hat{b} = \frac{\sum_{j=1}^{J_n} (l_{zj} - m_j l_{cj})}{\sum_{j=1}^{J_n} (1 - m_j)},$$

where J_n is the number of whales seen in both the zoomed and counting video, and j is the index of the jth pair. If b was not significantly different from zero, it was not necessary to correct for bias.

The following equation was then used to estimate the image size in the counting video for the whales that were visible in the zoomed video but, because of their size, were not detected in the counting video. The estimated image size for these whales in the counting video was:

$$\hat{l}_c = \frac{l_z - \hat{b}}{m} + \hat{b}.$$

A binomial logistic regression was applied to the resulting combined distribution of measured and estimated standard image sizes to estimate the probability that a whale with a given image size would be seen in the counting video.

For a given group, g, and pass, p, m is not known. Instead, the average of image sizes, $\mu_{g,p}$, and the fractions of whales that would be detected , $F(\mu_{g,p})$, in a counting video are related. To determine this relationship, arbitrary values for magnification, m', (e.g. magnification increasing at 0.01 intervals) are chosen to span the range of possible magnifications. The combined distribution of observed (whales seen in both the zoomed and counting video) and estimated (whales seen in the zoomed but missed in the counting because of small size) counting video sizes are then rescaled by

$$\hat{l}_{m'j} = (l_{cj} - \hat{b})m' + \hat{b}$$

to simulate the distribution of image sizes under these arbitrary magnifications. For this re-scaled distribution, the average of image sizes, $\mu(m')$, and the fractions of whales, $F(\mu(m'))$, that would be detected in a counting video are

$$\mu(m') = \frac{\sum_{J_n+J_w} P(\hat{l}_{m'j})\hat{l}_{m'j}}{\sum_{J_n+J_w} P(\hat{l}_{m'j})},$$

$$F(\mu(m')) = \frac{\sum_{J_n+J_w} P(\hat{l}_{m'j})}{J_n + J_w},$$

where $P(l)$ is the probability that an image of size l will be seen in the counting video.

A lookup table relating average image size for a group counted from video, $\mu_{g,p}$, to the correction for the fraction that were missed because of image size, $1/F(\mu_{g,p})$, was created from this analysis. For passes with a sample of measured images, the fraction missed was found in the table. Passes of small groups where images were not measured were given the average fraction missed from other passes of the same group, or if no other passes on the group had measured images, the pass was given the average fraction missed of all measured passes from all groups.

Combined Correction Factor

The correction for perception bias was the product of the proximity correction and the image size correction. For a video count with an estimated average image size, $\hat{\mu}_{gp}$, the correction factor, $D_{g,p}$ is then,

$$D_{gp} = \left[\frac{J_z}{J_z - J_p}\right]\frac{1}{F(\hat{\mu}_{gp})}.$$

Correction for Availability

The formula of McLaren (1961) for the correction for availability bias is the inverse of the probability that a typical beluga is at or will appear at the surface during the videotaping. The correction factor, $A_{g,p}$, for a group and pass depending on the time spent counting, $t_{g,p}$, is calculated as,

$$A_{g,p} = \frac{T_1}{T_s + t_{g,p}},$$

where T_1 is the average dive interval (24.1 sec., Lerczak et al., 2000), and T_s is the average time at the surface from the video analysis described above.

Estimation of Group Size

The group size, $\hat{n}_g$, was estimated by averaging the corrected video counts for a group:

$$\hat{n}_g = \frac{1}{P_g}\sum_{P_g} c_{g,p} D_{g,p} A_{g,p},$$

where, $c_{g,p}$ is the count for group g from pass p, and P_g is the number of passes for group g that were counted. When a video pass contained two or more distinctly different segments (e.g. it began using the point method, then switched to the scan method when the first portion of the group came abeam of the plane), the counts were corrected separately to create a group size estimate for each subgroup. These subgroup estimates were then summed to estimate the total group size.

The coefficient of variation (CV) for $\hat{n}_g$ was estimated as:

$$CV(\hat{n}_g) = \sqrt{\frac{\overline{CV}^2(n)}{P_g} + \overline{CV}^2(D_g) + \overline{CV}^2(A_g)}.$$

An average CV for a group size estimate made from a single count was estimated by averaging the variation of the group size estimates of all groups where more than one pass from the group was counted from video,

$$\overline{CV}^2(n) = \frac{\sum_{G2} \frac{1}{P_g - 1} \sum_{P_g} (n_{g,p} - \bar{n}_g)^2}{\sum_{G2} \bar{n}_g^2}.$$

Where more than one count is used to estimate group size, this average CV is

scaled appropriately. The value CV(n) includes an empirical measure of stochastic variation between counts that is not corrected by the two correction factors, but it does not account for the variation of the correction factors themselves which must be accounted for separately.

The component of the CV resulting from the correction for perception, CV(D_g), is estimated by the delta method as,

$$\overline{CV}^2(D_g) = \frac{\sum_{P_g}\left[\left.\frac{\partial D}{\partial \mu}\right|_{\mu_{g,p}}\right]^2 SE^2(\mu_{g,p})}{\left[\sum_{P_g} D_{g,p}\right]^2}.$$

For cases where $\mu_{g,p}$ was not estimated, the correction factor $D_{g,p}$ was derived from an average of $\mu_{g,p}$ from other passes of the same group or an average of other groups. In these cases $SE(\mu_{g,p})$ was the standard deviation of the set of the estimated average image sizes of the averaged groups.

The component of the CV resulting from the correction for availability, CV(D_g), is dominated by the variation of T_I. The variation of T_I has a component related to the variability between individuals and the variation of a typical individual. Following the delta method yields,

$$\overline{CV}^2(A_g) = \frac{\sum_{P_g}\left[\frac{1}{T_s + t_{g,p}} SE_g(T_I)\right]^2}{\left[\sum_{P_g} A_{g,p}\right]^2} = \frac{\frac{\sigma_A^2 - \sigma_I^2}{\hat{n}_g}\sum_{P_g}\left[\frac{1}{T_s + t_{g,p}}\right]^2}{\left[\sum_{P_g} A_{g,p}\right]^2},$$

where σ_A^2 (= 41 sec^2, σ_A = 6.4 sec) and σ_I^2 (= 707 sec^2, σ_I = 26.6 sec) are the variance of the average dive interval among individuals and the average variance of the dive interval of individuals, respectively (values taken from Lerczak et al., 2000). Note that in this formulation, CV(A) was not independent of group size because of the assumption that the dive behavior of individuals in the group is uncorrelated so that the variation in the average of dive intervals during the counting interval decreases as group size increases.

Group Size Estimates from Observer Counts

Good quality video was not available for all groups, so a method for estimating group size from observer counts was devised. Aerial counts of beluga whales were corrected for observer differences and the effect of encounter rate (group density in whales per second). Data from observers who had participated in the equivalent of one or more complete survey seasons (three surveys of the upper inlet and one survey of the lower inlet) were included in the analysis. Only counts made during passes considered by the observers to be excellent or good in quality (A or B) were used. Group sizes, estimated from video recordings, were used to represent the true group size.

This method provided a correction for availability and perception as well as the uncertainty in the time available to observers to count individual whales. The correction formula was derived by regression of the video-derived group sizes against the observer counts for those groups and an interaction term between the counts and the observed encounter rate with the intercept fixed at zero:

$$\hat{n}_{g,p,o} = c_{g,p,o}\left(\hat{b}_{1,o} + \hat{b}_{2,o}\frac{c_{g,p,o}}{t_{g,p}}\right)$$

$$Var(\hat{n}_{g,p,o}) = c_{g,p,o}^2\left(\begin{array}{c} SE^2(\hat{b}_{1,o}) \\ +2Cov(\hat{b}_{1,o}\hat{b}_{2,o})\frac{c_{g,p,o}}{t_{g,p}} \\ +SE^2(\hat{b}_{2,o})\frac{c_{g,p,o}^2}{t_{g,p}^2}\end{array}\right),$$

where $\hat{n}_{g,p,o}$ is the size estimate for group g from a count by observer o during pass p, $\hat{b}_{1o}$, $\hat{b}_{2o}$ are the parameters estimated for each observer by linear regression, $C_{g,p,o}$ is the count by observer o of group g during pass p, $t_{g,p}$ is the time spent counting group g during pass p, $SE^2(\hat{b})$ is the squared standard error of the regression coefficients, $\hat{b}_{1,o}$, $\hat{b}_{2,o}$, and $Cov(\hat{b}_{1,o}, \hat{b}_{2,o})$ is the estimated covariance of the regression coefficients, $\hat{b}_{1,o}$, $\hat{b}_{2,o}$.

This approach weights the correction formula to be most accurate for large groups where a bias would have the greatest impact on the abundance estimate. The first summand estimates a multiplicative correction for counts to group size; the second summand estimates an additive bias proportional to the count multiplied by the density of the group. For aerial counts without recorded time, a single multiplicative correction was also estimated. The correction formula was applied to counts from groups where no group size estimate was available through the video analysis. These corrected counts were then averaged to estimate the group size:

$$\hat{n}_g = \frac{\sum_{J_g}\hat{n}_{g,p,o}}{J_g}$$

$$Var(\hat{n}_g) = \frac{\sum_{J_g}(\hat{n}_g - \hat{n}_{g,p,o})^2}{J_g - 1} + \frac{\sum_{J_g} Var(\hat{n}_{g,p,o})}{J_g^2},$$

where $\hat{n}_g$ is the estimated size of group g, and J_g is the set of corrected observer counts for group g.

Results

Aerial Counts

There were 144 sightings of beluga whale groups during aerial surveys of Cook Inlet in 1994–2000 (Table 1). Many of these represent multiple resightings of groups encountered on different survey days and years. Of the 144 sightings, 126 were counted and video

Table 1.—Beluga whale group size estimates made from aerial surveys of Cook Inlet, Alaska, 1994–2000. Count method refers to either group size estimates made from video counts only (Vid.) or from corrected observer counts (Obs.). Elapsed times are: video point passes (P), video scan passes (S), observer counts (O), or elapsed time not available (na). Correction factors for group size estimates made from video counts were calculated for each pass separately with group averages given here. For groups with no usable video, group size was estimated from observer counts using a formula derived by regression of counts vs. group size where video was available (see Table 2 for parameters).

Date	Group	Location	Count method	Average group count	Number of counts	Average elapsed time during count (sec)	Correction for subsurface whales (A)	CV(A)	Correction for whales missed at the surface (D)	CV(D)	CV (video count)	Estimated group size (N_g)	CV(N_g)
6/1/94	1	Big Susitna	Vid.	156	4	17.98 (P)	1.22	0.13	1.12	0.01	0.11	209	0.17
6/1/94	2	Big Susitna	Vid.	145	1	14.00 (P)	1.46	0.22	1.24	0.04	0.21	263	0.31
6/2/94	1	W of Big Susitna	Obs.	119	4	na						394	0.6
6/2/94	2	Turnagain Arm	Obs.	6	4	na						18	0.47
6/2/94	3	Chickaloon Bay	Obs.	15	4	na						47	0.43
6/3/94	1	Pt Possession	Obs.	10	5	38.00 (O)						27	0.39
6/3/94	2	Kachemak Bay	Obs.	3	5	21.00 (O)						8	0.31
6/3/94	3	Kachemak Bay	Obs.	5	3	25.00 (O)						13	0.29
6/4/94	1	Iniskin Bay	Obs.	2	4	25.67 (O)						4	0.3
6/4/94	2	W of Big Susitna	Obs.	59	4	20.50 (O)						144	0.31
6/4/94	3	Big Susitna	Vid.	155	2	14.97 (P)	1.38	0.17	1.17	0.02	0.15	252	0.22
6/4/94	4	W of Little Susitna	Vid.	123	1	11.50/4.60 (P/S)	3.39	0.11	1.14	0.02	0.21	475	0.24
6/5/94	1	Pt Possession/E Foreland	Obs.	1	3	11.00 (O)						2	0.93
6/5/94	2	Beluga R	Vid.	16	1	17.60/8.40 (P/S)	2.21	0.45	1.16	0.09	0.21	41	0.51
6/5/94	3	W of Big Susitna	Vid.	16	1	19.80 (P)	1.08	0.94	1.16	0.09	0.21	20	0.96
6/5/94	4	W of Big Susitna	Obs.	9	6	17.00 (O)						21	0.34
6/5/94	5	W of Big Susitna	Vid.	29	1	31.47/12.70 (P/S)	1.59	0.46	1.19	0.02	0.21	55	0.51
6/5/94	6	Little Susitna	Obs.	145	6	38.50 (O)						337	0.19
6/5/94	7	Chickaloon	Vid.	6	1	65.93/13.38 (P/S)	1.52	1.08	1.16	0.09	0.21	11	1.1
7/18/95	1	Chickaloon	Vid.	18	5	15.97 (P)	1.36	0.34	1.26	0.03	0.09	29	0.36
7/18/95	2	McArthur R	Obs.	1	8	25.60 (O)						1	1.15
7/18/95	3	Big Susitna	Obs.	331	7	97.71 (O)						731	0.36
7/19/95	1	Chickaloon	Vid.	14	6	17.27 (S)	1.42	0.39	1.16	0.04	0.09	20	0.41
7/19/95	2	McArthur R	Obs.	4	5	20.00 (O)						8	0.58
7/19/95	3	Shirleyville	Obs.	4	1	na						4	0.42
7/19/95	4	Big Susitna	Vid.	101	2	14.88 (S)	1.72	0.12	1.35	0.1	0.15	348	0.22
7/20/95	1	Chickaloon	Vid.	7	4	8.95 (S)	2.11	0.38	1.16	0.05	0.11	16	0.4
7/20/95	2	Big Susitna	Vid.	48	1	17.00 (P)	1	0.45	1.23	0.03	0.21	73	0.5
7/20/95	3	Big Susitna	Obs.	104	5	56.40 (O)						309	0.41
7/21/95	1	Big Susitna (E)	Vid.	18	1	13.00 (S)	1.55	0.61	1.16	0.09	0.21	32	0.65
7/21/95	2	Big Susitna (W)	Obs.	132	5	109.71 (O)						278	0.77
7/21/95	3	Knik Arm	Obs.	2	1	na						2	0.42
7/21/95	4	Chickaloon	Obs.	18	8	22.75 (O)						43	0.26
7/22/95	1	Big R	Vid.	9	4	12.29 (S)	1.75	0.41	1.16	0.05	0.11	17	0.42
7/24/95	1	Drift R	Obs.	2	5	18.50 (O)						5	1.05
7/24/95	2	McArthur R	Obs.	2	12	11.83 (O)						4	0.68
7/24/95	3	Big Susitna (W)	Vid.	86	1	32.50/7.00 (P/S)	2.54	0.16	1.25	0.03	0.21	272	0.27
7/24/95	4	Big Susitna (E)	Obs.	34	7	30.00 (O)						94	0.45
6/11/96	1	S of Beluga R	Obs.	2	1	na						2	0.42
6/11/96	2	Lewis R	Obs.	6	6	18.00 (O)						13	0.69
6/11/96	3	Ivan R	Obs.	2	1	na						2	0.42
6/11/96	4	Theodore R	Obs.	4	3	20.67 (O)						9	0.49
6/11/96	5	Lewis R	Obs.	117	13	115.33 (O)						256	0.25
6/12/96	1	Knik Arm	Obs.	5	5	17.33 (O)						12	0.39
6/12/96	2	Knik Arm	Obs.	2	1	na						4	0.42
6/12/96	3	Big Susitna (after stranding)	Vid.	43	2	19.50/8.53 (P/S)	1.64	0.3	1.16	0.07	0.15	69	0.34
6/12/96	4	Pt Possession	Obs.	17	1	na						48	0.58
6/12/96	5	Lewis R	Obs.	138	12	83.14 (O)						304	0.29
6/12/96	6	Theodore R	Obs.	17	9	28.20 (O)						12	0.39
6/12/96	7	Lewis R	Vid.	32	2	25.03 (P)	0.88	0.58	1.16	0.07	0.15	33	0.6
6/12/96	8	Big Susitna R	Obs.	73	2	52.50 (O)						199	0.186
6/12/96	9	Big Susitna R	Obs.	20	5	40.75 (O)						47	0.294
6/13/96	1	Knik Arm	Obs.	7	7	25.50 (O)						17	0.26
6/13/96	2	Knik Arm	Obs.	8	7	24.50 (O)						18	0.45
6/13/96	3	Pt Possession	Vid.	26	3	9.58 (S)	2.13	0.22	1.16	0.05	0.12	69	0.26
6/13/96	4	Ivan R	Obs.	80	8	36.25 (O)						168	0.2
6/13/96	5	Big Susitna R	Vid.	79	3	7.39 (S)	2.6	0.1	1.16	0.05	0.12	229	0.17
6/14/96	1	Pt MacKenzie	Obs.	18	6	24.00 (O)						39	0.39
6/16/96	1	Knik Arm	Obs.	17	6	17.80 (O)						37	0.15
6/16/96	2	Knik Arm	Obs.	13	10	83.60 (O)						28	0.32
6/16/96	3	Pt Possession	Vid.	15	2	6.77 (P/S)	2.32	0.32	1.16	0.07	0.15	40	0.36
6/16/96	4	Lewis/Ivan R	Vid.	107	8	5.36 (S)	3.08	0.05	1.12	0.01	0.07	365	0.09
6/16/96	5	Big Susitna	Vid.	34	4	11.24 (P/S)	1.75	0.2	1.16	0.05	0.11	69	0.23
6/16/96	6	Big/ Little Susitna	Obs.	55	8	32.50 (O)						132	0.39
6/16/96	7	Little Susitna	Vid.	21	2	21.74 (P)	1.02	0.73	1.16	0.07	0.15	22	0.74
6/17/96	1	Ivan/ Big Susitna	Vid.	125	2	5.07 (S)	3.25	0.08	1.11	0.01	0.15	446	0.17
6/17/96	3	Little Susitna	Vid.	22	3	18.28 (P)	1.19	0.42	1.15	0.02	0.12	30	0.44
6/17/96	4	Ivan/ Big Susitna	Vid.	65	1	15.50/5.38 (P/S)	3.06	0.16	1.16	0.09	0.21	230	0.28
6/8/97	1	Knik Arm	Vid.	14	3	13.27/4.70 (P/S)	2.14	0.31	1.1	0.01	0.12	30	0.34
6/8/97	2	Knik Arm	Vid.	35	5	17.50/12.64 (P/S)	1.41	0.21	1.29	0.02	0.09	63	0.23
6/8/97	3	Knik Arm	Vid.	42	5	26.50/9.42 (P/S)	1.8	0.18	1.17	0.01	0.09	76	0.2

Continued on next page.

Table 1.—Continued.

Date	Group	Location	Count method	Average group count	Number of counts	Average elapsed time during count (sec)	Correction for subsurface whales (A)	CV(A)	Correction for whales missed at the surface (D)	CV(D)	CV (video count)	Estimated group size (N_g)	CV(N_g)
6/8/97	4	Knik Arm	Obs.	1	1	na						2	0.42
6/8/97	5	Knik Arm	Vid.	35	5	8.90 (S)	2.18	0.18	1.18	0.01	0.31	96	0.4
6/8/97	7	Knik Arm	Obs.	4	1	na						4	0.42
6/8/97	8	Chickaloon	Vid.	11	6	16.20/8.28 (P/S)	2.02	0.31	1.19	0.02	0.09	20	0.32
6/8/97	9	Chickaloon	Vid.	9	4	17.12/9.47 (P/S)	1.73	0.42	1.19	0.01	0.11	19	0.43
6/8/97	10	Big Susitna	Vid.	49	3	9.30 (S)	2.1	0.17	1.21	0.03	0.12	127	0.21
6/9/97	1	Tuxedni Bay	Obs.	2	1	na						2	0.42
6/9/97	2	Big Susitna	Obs.	58	9	37.67 (O)						103	0.36
6/10/97	1	Chickaloon	Vid.	30	4	4.87 (S)	3.3	0.12	1.14	0.01	0.11	113	0.16
6/10/97	2	Big Susitna	Obs.	70	15	57.75 (O)						140	0.35
6/10/97	3	Knik Arm	Vid.	67	7	9.37 (S)	2.15	0.09	1.14	0.01	0.08	153	0.12
6/10/97	4	Knik Arm	Vid.	30	5	26.50/8.06 (P/S)	2.03	0.19	1.18	0.02	0.09	60	0.21
6/10/97	5	Knik Arm	Obs.	1	1	na						2	0.42
6/10/97	6	Knik Arm	Obs.	5	2	na						9	0.42
6/9/98	1	Little Susitna	Vid.	59	1	18.00 (S)	1.18	0.45	1.13	0.02	0.21	78	0.5
6/10/98	1	Fire I	Obs.	11	8	13.25 (O)						21	0.52
6/10/98	2	Chickaloon	Vid.	14	5	12.38 (S)	1.62	0.31	1.16	0.04	0.09	27	0.33
6/10/98	3	Susitna	Vid.	75	3	16.36 (S)	1.45	0.19	1.23	0.02	0.12	139	0.23
6/10/98	4	Knik	Obs.	4	1	na						4	0.42
6/10/98	5	Knik	Obs.	11	4	18.00 (O)						21	0.39
6/10/98	6	Knik	Obs.	4	4	15.00 (O)						7	0.48
6/10/98	7	Knik	Obs.	4	5	26.67 (O)						8	0.41
6/10/98	8	Knik	Obs.	30	3	29.00 (O)						64	0.42
6/10/98	9	Knik	Obs.	6	2	31.00 (O)						9	0.5
6/10/98	10	Knik	Obs.	24	5	24.67 (O)						49	0.33
6/12/98	1	Little Susitna	Vid.	26	4	11.74 (S)	1.8	0.26	1.21	0.02	0.11	53	0.28
6/12/98	2	Knik	Obs.	5	5	16.75 (O)						9	0.89
6/12/98	3	Knik	Vid.	14	2	12.54 (S)	1.89	0.43	1.16	0.07	0.15	26	0.46
6/12/98	4	Knik	Vid.	10	3	11.20 (S)	1.93	0.51	1.16	0.05	0.12	18	0.53
6/12/98	5	Knik	Vid.	8	3	7.49 (S)	2.54	0.34	1.16	0.05	0.12	21	0.37
6/12/98	6	Knik	Obs.	9	4	64.25 (O)						19	0.66
6/12/98	7	Knik	Vid.	19	1	9.33 (S)	2.04	0.45	1.16	0.09	0.21	45	0.51
6/12/98	8	Chickaloon	Vid.	16	3	12.19 (S)	1.74	0.38	1.16	0.05	0.12	31	0.4
6/12/98	9	Chickaloon	Vid.	14	2	18.33 (S)	1.16	0.66	1.15	0.02	0.15	19	0.68
6/15/98	1	Chickaloon	Vid.	34	3	8.35 (S)	2.34	0.18	1.18	0.02	0.12	89	0.22
6/15/98	2	Little Susitna	Obs.	2	1	na						2	0.42
6/15/98	3	Little Susitna	Vid.	132	4	11.24 (S)	1.79	0.1	1.21	0.01	0.11	285	0.14
6/15/98	4	Knik	Obs.	12	3	na						21	0.42
6/15/98	5	Knik	Vid.	16	7	9.69 (S)	2.13	0.2	1.16	0.04	0.08	40	0.21
6/15/98	6	Knik	Vid.	2	2	8.20 (S)	2.29	1.07	1.16	0.07	0.15	4	1.08
6/15/98	7	Knik	Vid.	5	5	9.51 (S)	2.05	0.65	1.16	0.04	0.09	11	0.66
6/9/99	1	Little Susitna	Vid.	123	6	8.05(S)	2.62	0.03	1.08	0.00	0.17	314	0.17
6/9/99	2	Knik Arm	Obs.	23	3	na						55	0.11
6/9/99	3	Chickaloon	Vid.	16	1	11.60(S)	1.71	0.21	1.06	0.00	0.40	29	0.46
6/11/99	1	Little Susitna	Vid.	72	1	5.00(S)	3.21	0.07	1.06	0.00	0.40	245	0.41
6/12/99	1	Chickaloon	Vid.	1	4	7.25(S)	2.62	0.36	1.19	0.14	0.20	3	0.44
6/12/99	2	Chickaloon	Vid.	16	6	16.76(S)	1.63	0.09	1.14	0.02	0.17	30	0.19
6/12/99	4	Beluga R.	Vid.	7	1	14.00(S)	1.46	0.32	1.24	0.00	0.40	13	0.52
6/12/99	5	Big Susitna	Vid.	31	4	6.94(S)	2.73	0.06	1.06	0.00	0.20	92	0.21
6/12/99	6	Little Susitna	Vid.	69	1	7.33(S)	2.45	0.08	1.06	0.00	0.40	179	0.41
6/12/99	7	Knik Arm	Vid.	19	3	13.33(S)	1.69	0.11	1.20	0.00	0.23	39	0.26
6/13/99	1	Big Susitna	Vid.	16	2	14.53(S)	1.42	0.16	1.15	0.00	0.29	25	0.33
6/13/99	2	Little Susitna	Vid.	165	4	15.41(P)	1.46	0.04	1.13	0.00	0.20	258	0.21
6/13/99	4	Knik Arm	Vid.	15	5	22.16(P)	1.35	0.14	1.15	0.00	0.18	18	0.23
6/7/00	1	Knik	Vid.	18	3	10.00 (P/S)	1.87	0.10	1.34	0.15	0.24	44	0.30
6/7/00	2	Knik	Vid.	9	5	8.40 (S)	2.28	0.10	1.18	0.05	0.19	25	0.22
6/8/00	1	Little Susitna	Vid.	109	8	09.12 (P/S)	2.37	0.02	1.25	0.07	0.15	317	0.16
6/8/00	2	Little Susitna	Vid.	22	3	18.67 (P/S)	1.17	0.12	1.24	0.05	0.24	33	0.27
6/8/00	3	Chickaloon	Vid.	4	2	5.00 (S)	3.32	0.24	1.11	0.03	0.30	11	0.38
6/11/00	1	Little Susitna	Vid.	86	9	8.00 (S)	2.37	0.03	1.15	0.04	0.14	231	0.15
6/11/00	2	Beluga River	Vid.	1	5	12.40 (S)	1.77	0.35	1.27	0.09	0.19	2	0.41
6/12/00	1	Chickaloon	Vid.	11	8	9.25 (S)	2.28	0.08	1.26	0.11	0.15	31	0.20
6/12/00	2	Chickaloon	Vid.	4	5	6.60 (S)	2.86	0.16	1.13	0.04	0.19	11	0.25
6/12/00	3	Little Susitna	Vid.	131	8	7.50 (S)	2.52	0.02	1.11	0.02	0.15	357	0.15
6/12/00	4	Little Susitna	Vid.	7	1	4.00 (S)	3.61	0.22	1.08	0.02	0.42	27	0.47
6/12/00	5	Knik	Obs.	5	2	na						13	0.79
6/12/00	6	Knik	Vid.	1	1	6.00 (S)	3.00	0.61	1.16	0.09	0.42	3	0.74
6/12/00	7	Knik	Vid.	20	5	9.80 (S)	2.00	0.07	1.26	0.07	0.19	49	0.21
6/13/00	1	Chickaloon	Obs.	4	2	52.00 (O)						9	0.51
6/13/00	2	Big Susitna	Vid.	51	6	7.67 (S)	2.40	0.04	1.31	0.06	0.17	156	0.18
6/13/00	3	Knik	Obs.	7	2	53.50 (O)						18	0.32
6/13/00	4	Knik	Obs.	3	1	na						9	0.68
6/13/00	5	Knik	Vid.	8.6	5	6.00 (S)	2.88	0.10	1.14	0.08	0.19	28	0.22

recorded following the survey protocol. The remaining were either: 1) small groups (<10) encountered in areas of high aircraft traffic, where groups could not be circled due to safety concerns, or 2) groups encountered during non-survey flights (e.g. in support of vessel operations or as a part of adjunct experiments). Video of sufficient quality for group size estimates was available for 79 groups, averaging 3.5 (SD=2.1) counts per group. Average count times ranged from 4 sec to 13 sec for scan counts and from 6 sec to 65 sec for point counts. The remaining 65 group size estimates were derived from observer counts, averaging 4.7 (SD= 3.2) counts per group with count times ranging from 11 sec to 115 sec.

Linear regression, comparing observer counts to counts from video for the years 1994–98, indicated significant effects for each of the covariates: count ($\hat{b}_{1,o}$) and count multiplied by encounter rate ($\hat{b}_{2,o}$). All but one of the individual observer parameters for the count correction were significant, and for three observers, the parameter in the adjustment for encounter rate was significantly different from zero (Table 2). The video recordings in 1999 and 2000 were so successful that sizes for all but a few small groups were obtained from video. Sample sizes for comparison between the video-derived group sizes and observer counts within each year were sufficiently large so that each year was treated separately in the linear regression analysis (Table 2). Group sizes were then estimated for groups which had no group size available from video.

Table 2.—Parameters used to estimate beluga whale group sizes based on the observers' counts and the time spent counting each group. When there was no record of time spent counting, the respective aerial count was multiplied by the simple correction. $\hat{b}_{1,o}$ is the parameter used to estimate each observer's counting performance. $\hat{b}_{2,o}$ is the correction of counts as a function of group size. In 2000, none of the $\hat{b}_{2,o}$ parameters were significant, so only the simple corrections were used.

Years	Observer	Simple correction	SE	$\hat{b}_{1,o}$	SE	$\hat{b}_{2,o}$	SE
1994–98	1	2.01	(0.10)	1.80	(0.13)	0.07	(0.03)
	2	2.43	(0.28)	2.88	(1.61)	–0.60	(2.11)
	3	3.77	(0.38)	2.60	(0.65)	0.17	(0.08)
	4	2.84	(0.16)	2.60	(0.39)	0.12	(0.18)
	5	1.58	(0.07)	2.25	(0.28)	–0.18	(0.07)
	6	2.82	(1.64)	2.04	(0.58)	0.41	(0.29)
	7	1.43	(0.22)	1.45	(0.70)	0.00	(0.19)
	8	2.82	(0.29)	1.59	(0.79)	0.60	(0.36)
1999	1	2.68	(0.16)	2.07	(0.52)	0.24	(0.20)
	4	2.19	(0.11)	2.24	(0.33)	–0.02	(0.10)
	5	2.41	(0.11)	1.97	(0.23)	0.14	(0.07)
	8	2.80	(0.17)	1.56	(0.54)	0.56	(0.23)
2000	1	2.45	(0.10)				
	4	2.90	(0.09)				
	5	2.87	(0.16)				
	8	2.83	(0.14)				

Video Counts, Time-at-the-surface, and Image Size

A total of 275 passes representing 79 groups were counted using aerial video recordings and a total of 2,775 whales were measured in the counting video. The average time-at-the-surface for all of the whales that were measured was 2.34 sec (SD=0.94, SE=0.018). This value, rounded to the nearest 0.5 sec (T_s = 2.5 sec), was used in the correction for whales missed under the water's surface. The average image size was 1.76 mm (SD=0.46, SE=0.009).

Zoomed vs. Counting Video and Correction for Whales Missed at the Surface

Two of the three circling experiments provided enough zoomed images suitable for matching to the counting video. A whale group videotaped 13 June 1996 resulted in 103 usable whale images in the zoomed video, of which 91 were also seen in the counting video, 9 were not seen, and 3 were missed due to proximity to another whale that was counted. A group videotaped in 15 June 1998 resulted in 231 usable whale images in the zoomed video, of which 192 were also seen in the counting video, 29 were not seen, and 10 were missed due to proximity. The average whale image size between years was not significantly different (1996: 1.92 mm, SE=0.033 mm; 1998: 1.90 mm, SE=0.023), so the two data sets were combined into one size distribution.

Logistic regression estimated the probability that a whale image of a given size was seen as:

$$P(l) = \frac{e^{-13.72+9.56l}}{1+e^{-13.72+9.56l}}.$$

Thus an image of 1.43 mm in size would have a 50% chance of being seen in the counting video (Fig. 3). There was a poor correspondence between the gray-scale codes given to the images in the zoomed and counting videos. Gray belugas always appeared gray, but white belugas in the zoomed video would sometimes appear gray in the counting video when their image size was small. Therefore, gray-scale codes were not used to stratify this analysis, and the ratio of gray to white images in the counting video is not considered to be representative of the ratio of juveniles to adults in the population. The correction for missed whales at the surface, by average image size is fairly constant for larger values ($\mu > 3$ mm) but climbs quickly as the average image size declines below 2.5 mm (Fig. 4). This correction was not considered valid for values greater than 1.5 ($\mu < 1.63$ mm); however, there were no passes counted from videotape when average sizes were below this cutoff.

For groups counted from video using the Canon Hi-8 video camera (1994–98) this correction averaged 1.17 (SD=0.04) and ranged from 1.10 to 1.35 (Table 1). The component of this correction that corrected for whales missed due to image size averaged 1.13 (SD=0.04) and ranged from 1.06 to 1.30. The component related to whales missed due to proximity in the counting video was 1.04 (CV=0.01).

Zoomed video of groups during counting passes in 2000 was of sufficient quality for comparison to the counting video (with the Sony Digital 8 camera). A total of 24 passes on 11 groups resulted in 170 usable whale

images in the zoomed video; of these, 154 were also seen in the counting video, 13 were not seen, and 3 were missed due to proximity to another whale that was counted. Accordingly, a logistic regression estimate of the probability that a whale image of a given size was seen was:

$$P(l) = \frac{e^{-5.77+7.00l}}{1+e^{-5.77+7.00l}}.$$

Thus an image of 0.834 mm in size would have a 50% chance of being seen in the counting video (Fig. 3b). Gray scale codes did not correspond sufficiently well between the images in the zoomed and counting videos and therefore were not used to stratify this analysis.

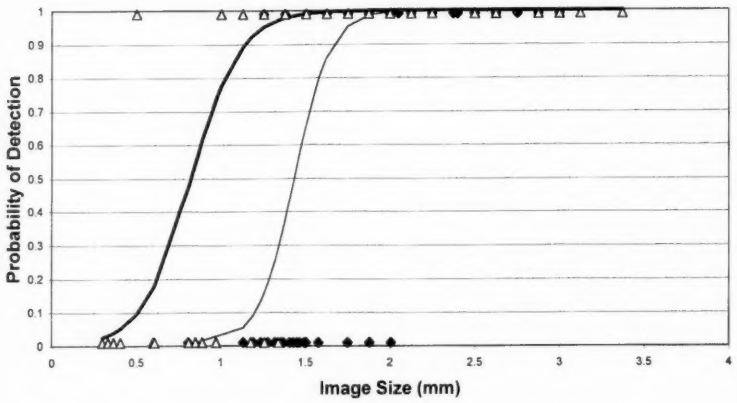

Figure 3.—Estimated probability from logistic regression of detection in the counting video by image size, with image sizes used in the analysis. Detected images are given a value of 1 and undetected images are given a value of 0. Diamonds represent 1994–98 data and triangles represent 1999–2000 data. The dark line is the probability of detection in the video from 1994–98, the light line is the probability of detection in the video from 1999–2000.

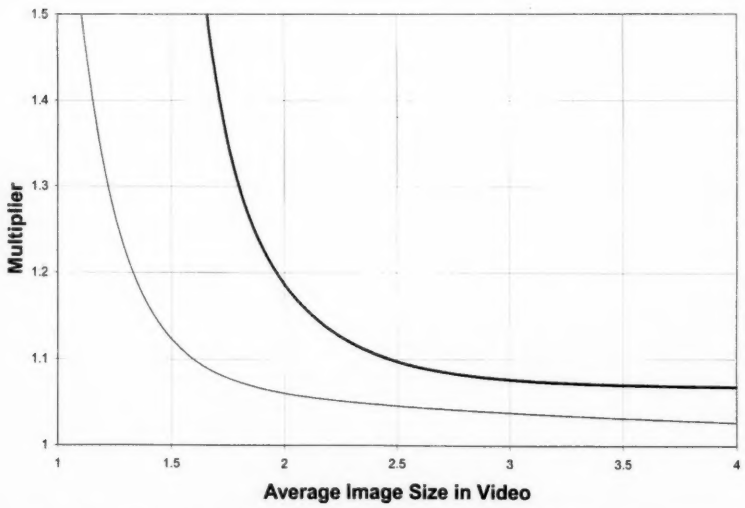

Figure 4.—Correction factors for beluga whales at the surface that were missed in the counting video, determined as a function of average image size of whales in the video counts for each pass of a group. This includes whales missed due to proximity to other whales and missed due to small image size. The dark line is the correction for the video from 1994–98, the light line is the correction for the video from 1999–2000.

The correction for missed whales at the surface, by average image size is fairly constant for larger values (μ > 2 mm) but climbs quickly as the average image size declines below 1.5 mm (Fig. 4). This correction was not considered valid for values greater than 1.5 (μ < 1.10 mm); however, there were no passes counted from videotape where average sizes fell below this cutoff. For groups counted from video using the Sony Digital 8 video camera (1999–2000), this correction averaged 1.17 (SD=0.08) and ranged from 1.06 to 1.34 (Table 1). The component of this correction that corrected for whales missed due to image size averaged 1.15 (SD=0.08) and ranged from 1.04 to 1.31. The component related to whales missed due to proximity in the counting video was 1.018 (CV=0.01).

Correction for Whales Missed Below the Surface in Video

Of the 275 passes counted from video, 30 were point counts, 189 were scan counts, and 56 were a mixture of scan and point. Point counts averaged 18.4 sec and ranged from 6 sec to 66 sec; scan counts averaged 9.7 sec and ranged from 4 sec to 30 sec. Correction factors for individual passes averaged 2.03 (SD=0.64) and ranged from 0.88 to 3.62 per whale at the surface.

Group Size Estimates

Group size estimates ranged from 1 to 731 (Table 1). CV's for group size estimates from video averaged 0.36 and ranged from 0.09 to 1.10. CV's for group size estimates from observer counts averaged 0.45 and ranged from 0.11 to 1.15. The largest component of the CV's of the group size estimates from video is CV(A), the correction for availability, averaging 0.28, which is largely determined by the uncertainty in the dive interval.

Discussion

Video-derived group size estimates proved to be a valuable tool for examining observer counts made from an aircraft. When confronted with large

groups, it was difficult for observers to quickly see and count each individual whale. Therefore, observers made quick estimates by tallying whales as best as they could.

Data from video counts indicate that for these large groups, too many whales were present for observers to mentally register each whale. Often, biased counts were made depending on the response of individual observers to this difficulty. The observer counts of relatively small groups (< 50 whales) were often larger than counts from the video but not larger than the corrected video group size estimates, suggesting that observers had more time to count individuals in small groups, and they could search a larger area than the video could record at any one time while scanning.

In making corrections for missed whales in the video analysis, it was necessary to have a measure of the portion of a group of whales that were actually visible in the video. Of the two ways that whales could be missed, it was far more likely that they were unavailable to be videotaped due to submersion than undetectable due to the resolution of the video camera.

The average correction factor for availability bias was 2.03 (SD=0.64), thus more than half of the whales in a typical group were missed because they were underwater, and in some groups more than 2/3 of the group were missed. By comparison, the average correction for whales missed at the surface was 1.17, or roughly 1/7 of the whales available to be recorded were missed. On the surface it would seem that a higher resolution video system would reduce these two corrections by providing: 1) a wider field of view, which would allow for longer scan times and more whales to surface in the view, and 2) a crisper image so that small whales would be easier to detect, and whales in close proximity would form more distinct images. Such a system was incorporated in the aerial survey program in 1999 and 2000 when it started using a digital video camera. This resulted in an improved resolution of over 40% when comparing the estimated probabilities by size in Figure 3, but it did not significantly change the average correction factors. What did change was the success rate of the video data collection, resulting in 84% of the group size estimates being made from video in 1999 and 2000, whereas 46% of estimates were made from video during 1994–98.

The measure of time-at-the-surface was necessary as a component in the correction factor for whales missed because they were underwater during the count. We found differences in surface times between whale groups, although two passes from the same group had similar surface times. There are several possible reasons for these differences. The behavior of the animals may have been different between groups (or in the same group on different days). Whales may have faster surfacing times when they are active (feeding or traveling) than when at rest, or they may have different surfacing times while feeding on different prey types (such as herding small fish in dense schools compared to targeting large, single fish). However, we were unable to determine the behavior of a whale group from the air, other than that they were clumped or spread out.

Surface times may also be different between groups due to differences in distance from the aircraft. The farther the group was from the aircraft, the smaller the whales appeared. They would, therefore, be less distinct when measuring surface times. The brightness of the day and the sea condition may also affect how well animals were seen. These weather conditions affect how whales contrast against the background water gray-scale. There could also have been a difference in the brightness settings of the video monitor during analysis. However, variation of the average surface times of passes and groups was small in comparison to the uncertainty in the dive interval and the half-second resolution of the counting time, so it was not necessary to estimate this separately for each pass.

The variability of dive intervals of individuals is problematic for variance calculations. Individual behavior may be correlated if all or most of the members of a group are engaged in the same activity; this component of the variance could remain constant regardless of group size. An example would be a group that was feeding and consequently taking longer dives; each individual would be diving for a longer time within its own range of variability. The variance of the average dive interval among individuals would still decline with the inverse of group size. It is unknown to what degree the dive behavior of individuals in a group is correlated. We do not see obvious patterns during aerial surveys, so we assume that—although small subgroups may have correlated behavior—the overall effect is negligible.

The gray-scale codes that were determined for the counting video did not correspond well to the codes given to the corresponding zoomed images. Zoomed images were a better record of the true shade of the whale, so the lack of good correspondence to the gray-scale codes of the counting video indicated that the counting video was not a useful record of the ratio of gray to white in a group of beluga whales (i.e. the ratio of juveniles to adults). The most likely reason is that sizes of whale images in the counting video are close to the limits of the resolution of the video system. Higher resolution in the new digital video system made these gray-scale codes more reliable, but in the size range where whales were most likely to be missed, there was little improvement.

Despite conscientious effort by observers to count as many whales as they could, it is apparent from the magnitude of the correction for each observer's group size estimates that a significant number of beluga whales were missed during aerial counts even among well-trained observers. The magnitude of this correction is considerably larger with untrained observers. The most likely explanation is that each observer can only effectively count in an area somewhat smaller than the area covered by a large group. The time spent counting any portion of the group was then only an unknown fraction of the time spent counting the whole group.

The McLaren formula was not appropriate for use with these data because the time available to count an individual whale was not well determined

(except in the video analysis). Whale groups were often spread over several kilometers of water, so the time spent counting was sometimes as much as a minute or more, but no area of water was in view for more than several seconds. Also, observers have noticed that when whale density was high, the effective field of view for counting was reduced, decreasing the time available to count each individual whale.

Using video analysis to develop correction factors resolved this problem because there was no limit to the amount of time available to study the image. A correction specific to each observer allowed for variation in the area that each observer searched during an aerial count and the different responses of individual observers to high densities of whales.

A stranding of a group of beluga whales on a mud flat during low tide on 12 June 1996 allowed a rare opportunity to compare a precise count from aerial video recording of the group when stranded (63) against the typical, systematic aerial observer and video counts (racetrack method) made after the tide returned, and the whales were able to swim away. The resultant corrected count from aerial video of the swimming whales (69; Table 1, group 3) compares well to the precise count (63) obtained from the video of the group when stranded. The average of observer counts for this group (31) after it was waterborne again provides an anecdotal correction factor estimate of 2.2 (= 69/31), which is consistent with the correction factors for observer counts obtained from the video passes used in the abundance estimates (Table 2).

Other authors have applied correction factors to calculate beluga abundance from aerial counts. Brodie (1971) used a factor of 1.4 based on observed diving behavior (not including hard-to-see juvenile whales). Sergeant (1973) estimated that belugas in fairly turbid water would be visible for about one-third of the time (i.e. a factor of 3), based on observations of whales one day at the mouth of the Churchill River. Fraker (1980) used a factor of 2 to account for belugas invisible beneath the surface, but he considered this "largely arbitrary." Kingsley (1998), in a review of surveys of belugas in the St. Lawrence River, used a minimum availability correction of 1.15 for whales that were not at the surface in aerial photographs, but this was to improve the conformity with visual estimates, not a correction for absolute abundance.

The most substantial correction factor, 2.75, was developed by Frost et al. (1985) through results from VHF tags kept 2 weeks on two beluga whales in Bristol Bay and the assumption that aerial observers have 10 sec to search an area. However, their technique was designed to correct for whales missed in small groups while making a single transect pass through a sample area.

Although the Cook Inlet surveys have continued to operate on straight flightlines when counting whales, the multiple fly-overs ("racetracks") allow ample time to determine the extent of each group. This provides a better counting situation as observers can concentrate their search on the known location of the respective group. The amount of time spent counting each group—typically 20–60 sec—is recorded and can be included in calculations of abundance.

In conclusion, use of video to count groups of beluga whales removes some of the uncertainty associated with aerial observer counts. The area of view is well defined, and the time spent counting an area can be precisely measured. Little subjectivity is involved in interpreting the images, and counts from video recordings are highly repeatable among trained video analysts. Associated variables necessary for correction factors, such as time-at-the-surface and average image size, can be easily measured. Yet, the average coefficient of variation for a single count is over 20%. A portion of this is the result of the binomial variation associated with the correction factors for missed animals; the remainder may be due to variations in group behavior that we are as yet unable to identify from the air.

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Beluga, *Delphinapterus leucas*, Habitat Associations in Cook Inlet, Alaska

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ABSTRACT—A review of available information describing habitat associations for belugas, Delphinapterus leucas, *in Cook Inlet was undertaken to complement population assessment surveys from 1993–2000. Available data for physical, biological, and anthropogenic factors in Cook Inlet are summarized followed by a provisional description of seasonal habitat associations. To summarize habitat preferences, the beluga summer distribution pattern was used to partition Cook Inlet into three regions. In general, belugas congregate in shallow, relatively warm, low-salinity water near major river outflows in upper Cook Inlet during summer (defined as their primary habitat), where prey availability is comparatively high and predator occurrence relatively low. In winter, belugas are seen in the central inlet, but sightings are fewer in number, and whales more dispersed compared to summer. Belugas are associated with a range of ice conditions in winter, from ice-free to 60% ice-covered water. Natural catastrophic events, such as fires, earthquakes, and volcanic eruptions, have had no reported effect on beluga habitat, although such events likely affect water quality and, potentially, prey availability. Similarly, although sewage effluent and discharges from industrial and military activities along Cook Inlet negatively affect water quality, analyses of organochlorines and heavy metal burdens indicate that Cook Inlet belugas are not assimilating contaminant loads greater than any other Alaska beluga stocks. Offshore oil and gas activities and vessel traffic are high in the central inlet compared with other Alaska waters, although belugas in Cook Inlet seem habituated to these anthropogenic factors. Anthropogenic factors that have the highest potential negative impacts on belugas include subsistence hunts (not discussed in this report), noise from transportation and offshore oil and gas extraction (ship transits and aircraft overflights), and water quality degradation (from urban runoff and sewage treatment facilities). Although significant impacts from anthropogenic factors other than hunting are not yet apparent, assessment of potential impacts from human activities, especially those that may effect prey availability, are needed.*

Introduction

The small population of belugas, *Delphinapterus leucas,* in Cook Inlet is geographically and genetically isolated from four other populations (also called stocks) that occur around Alaska (Hazard, 1988; O'Corry-Crowe et al., 1997). Unlike the other Alaska stocks, Cook Inlet belugas occupy a relatively restricted body of water, during at least the ice-free months, and are exposed to comparatively intense perturbations associated with human activities. In this way, they may be considered a corollary to the small population of belugas that inhabits the St. Lawrence River estuary in eastern Canada (Sergeant, 1986; Kingsley, 1998; Lesage et al., 1999). However, unlike the Canadian population, the ecology of belugas in Cook Inlet is poorly understood because, until recently, their viability was not a concern. A recent decline in abundance (Hobbs et al., 2000), distribution (Rugh et al., 2000), viability (Hill and DeMaster, 1998), and availability to Alaska Native hunters (Huntington, 2000) has aroused concern for the Cook Inlet beluga stock. As a result, NOAA's National Marine Fisheries Service (NMFS) published a notice of intent to conduct a status review for this population (NMFS, 1998), a part of which is the investigation of habitat use and potential human impacts.

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Belugas are seen in Cook Inlet most months of the year, but little information on distribution is available except for summer (Rugh et al., 2000). Recent surveys show that the summer range of Cook Inlet belugas is contracting, with very few whale sightings in the central and lower portions of the inlet in the 1990's compared with the mid 1970's (Rugh et al., 2000). Specifically, during June and July 1974–79, aggregations of belugas numbering from the 10's to 100's of individuals were seen in the central inlet (Calkins[1]), where none have been reported since summer surveys began in 1993 (Rugh et al., 2000). Belugas were seen in the central portion of the inlet during recent winter surveys, but were few in number (Hansen and Hubbard, 1999). Finally, while the full range of the Cook Inlet beluga stock may extend from the inlet to Yakutat Bay and Shelikof Strait (Hazard, 1988), sightings outside Cook Inlet are extremely rare (Laidre et al., 2000).

To characterize patterns of beluga habitat use, we stratified Cook Inlet into three regions based on sightings during summer surveys conducted from 1993 to 1999 (Rugh et al., 2000). Areas of high, moderate, and low beluga occur-

[1] Calkins, D. G. 1984. Susitna hydroelectric project final report: big game studies, vol. IX, belukha whale. Alaska Dep. Fish Game, Anchorage, Doc. 2328, 17 p.

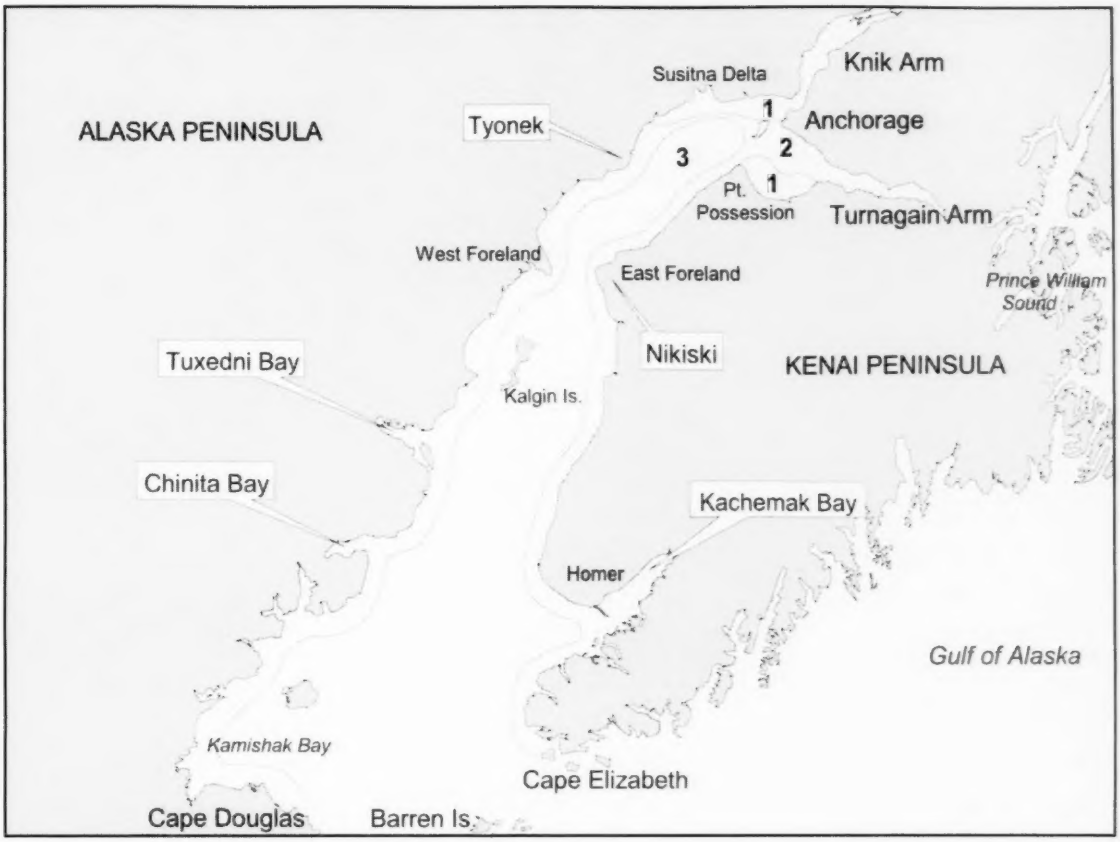

Figure 1.—Designation of three habitat regions based upon June and July distribution of belugas in Cook Inlet, Alaska; and place names mentioned in the text.

rence were defined, based upon whale distribution in June and July, and designated as Regions 1, 2, and 3, respectively (Fig. 1). Environmental information was summarized from published and unpublished data and a regional sampling survey carried out in the upper inlet in 1994 (Shelden and Angliss[2]).

Habitat associations are presented in three sections: 1) Physical Factors, including summaries of bathymetry and substrate; tides and current; salinity, turbidity, and temperature; tides and currents; natural catastrophic events (e.g. volcanoes, earthquakes, and fires), and ice cover associated with observed beluga distribution, 2) Biological Factors, including prey species and availability, predators, and natural mortality, and 3) Anthropogenic Factors, including fishing, oil and gas activities, transportation, and water quality.

Physical Factors

Cook Inlet is a semienclosed tidal estuary, extending roughly 370 km (200 n.mi.) southwest from Knik and Turnagain Arms to Kamishak and Kachemak Bays. The inlet has marine connections with Shelikof Strait and the Gulf of Alaska (GOA), and freshwater input from many large rivers (Muench et al., 1978). The shoreline of Cook Inlet is irregular, comprised of a series of channels, coves, flats, and marshes. To better characterize the estuarine environment used by Cook Inlet belugas, limited hydrographic and benthic sampling was conducted in June 1994, in the Susitna River delta during a beluga tagging study (Shelden and Angliss[2]). Measurements were taken opportunistically at sites close to beluga groups and at fixed stations (Fig. 2). Attempts were made to conduct repeat sampling at fixed stations at different times in the tidal cycle. Data collected during this short study supplement the section describing salinity, turbidity, and temperature.

Bathymetry and Substrate

Bathymetry of lower Cook Inlet (south of the Forelands) consists of an

[2] Shelden, K. E. W., and R. P. Angliss. 1995. Characterization of beluga whale (*Delphinapterus leucas*) habitat through oceanographic sampling of the Susitna River delta in Cook Inlet, Alaska, 11–18 June 1994. Int. Whal. Comm. Unpubl. Doc. SC/47/SM13, 10 p.

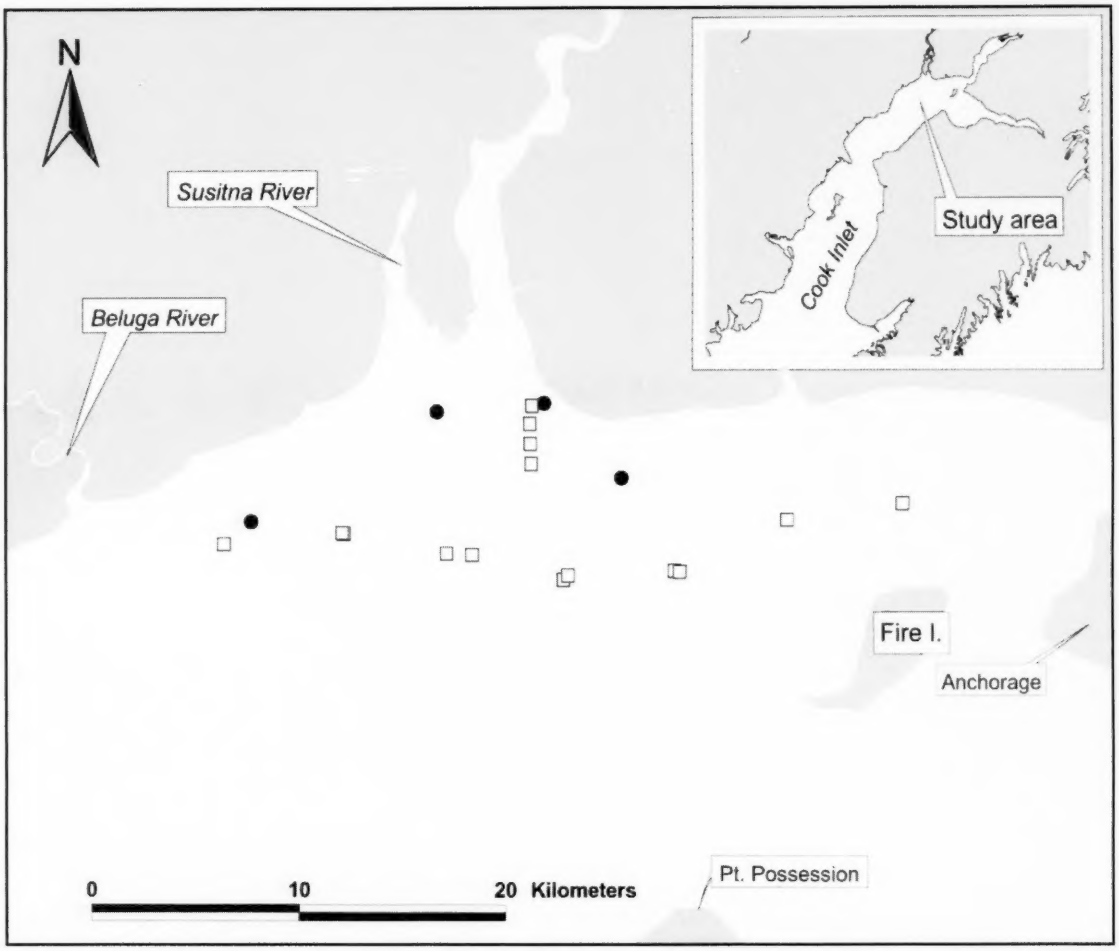

Figure 2.—Sites sampled for salinity and turbidity in upper Cook Inlet, June 1994. Dots are opportunistic sites, squares are fixed stations.

elongated trough (15–30 m deep) that bifurcates around Kalgin Island, with shallow platforms (≤10 m) on either side (Fig. 3). Northwest of Kalgin Island, a single narrow trough extends northwest mid inlet to about Trading Bay. South of Chinitna Bay, the main channel deepens to roughly 70–100 m and widens to extend across the mouth of Cook Inlet from Cape Douglas to Cape Elizabeth; it then slopes downward into Shelikof Strait. In contrast, the bathymetry of the inlet north of the Forelands is predominated by shallow river deltas.

Substrate in Cook Inlet is comprised of a mixture of cobbles, pebbles, sand, silt, and clay (Karlstrom, 1964). The inlet receives immense quantities of glacial sediment from the major rivers that empty into it (e.g. Knik, Matanuska, Susitna, Kenai, Kasilof, Beluga, McArthur, and Drift; Fig. 4). Rain and melting snow also contribute to the outflow of sediments. In addition, sediments of the Copper River drainage are carried into lower Cook Inlet and Shelikof Strait by the Alaska Coastal Current (ACC) (Schumacher et al., 1989). Longshore transport of sediment is generally into Cook Inlet, although this trend can be reversed by eddy features in Kamishak, Tuxedni, and Kachemak Bays. Sediment is then redistributed by intense tidal currents and often deposited on the extensive mud flats found in the upper inlet.

Salinity, Turbidity, and Temperature

Freshwater from rivers and land drainage, and seawater from the ACC, dominate the upper and lower portions of Cook Inlet, respectively. Salinity increases rapidly and almost uniformly from Anchorage to East and West Foreland (Fig. 4). During summer and autumn, salinity varies from about 26‰ at the Forelands to roughly 32‰ at the entrance to Cook Inlet (Gatto[3]). There

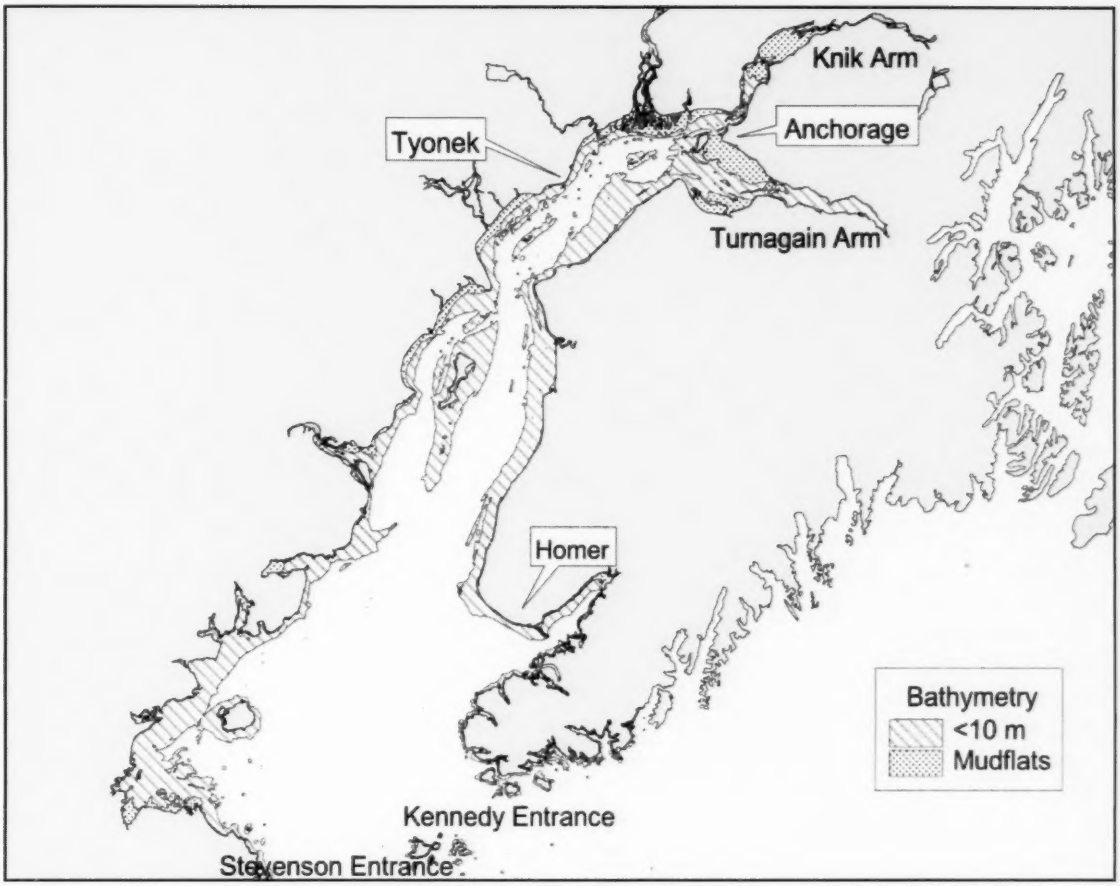

Figure 3.—Bathymetry of Cook Inlet, Alaska.

are characteristic isohalines (lines of equal salinity) resulting from high-salinity water on the eastern side and low-salinity water on the western side of Cook Inlet. In the lower inlet, isohaline contours vary with tidal currents, with local areas of depressed salinity near the mouths of large rivers and from glacially fed streams.

During our 1994 hydrographic study, beluga groups were generally found near river mouths in Regions 1 and 2 (Beluga, Susitna, and Little Susitna Rivers) where freshwater discharge and sediment loads strongly influence the hydrography. Samples obtained from stations close to beluga groups (which tended to be in water <3.5 m deep) had on average lower salinity and more suspended sediment than stations farther offshore (Fig. 5), similar to results obtained near the Port of Anchorage (Everts and Moore[4], USACE[5], Kinney et al.[6]). In June 1994, water temperatures were fairly uniform in nearshore and offshore waters of the upper inlet (Fig. 5). By July, temperatures in upper Cook Inlet usually warm to 14°–17°C (Bakus et al., 1979; USACE[5]) compared to the 8°–10°C sea surface temperatures at the mouth of the inlet and 11.5°–15°C in Kachemak Bay (Piatt, 1994).

Tides and Currents

Tides in Cook Inlet are semidiurnal, with two unequal high and low tides per tidal day (tidal day = 24 h 50 min). The mean diurnal tidal range varies from roughly 6 m (19 ft) at Homer to about 9.5 m (30 ft) at Anchorage. Three tidal rips (west, midchannel, and east)

[3] Gatto, L. W. 1976. Baseline data on the oceanography of Cook Inlet, Alaska. CRREL Rep. 76-25 prep. for NASA by U.S. Army Corps Engr., Cold Reg. Res. Engr. Lab., Hanover, N.H., 81 p.

[4] Everts, C. H., and H. E. Moore. 1976. Shoaling rates and related data from Knik Arm near Anchorage, Alaska. U.S. Army Corps Engr., Coast. Engr. Res. Cent., Fort Belvoir, Va., Tech. Pap. 76-1, 84 p.

[5] USACE (U.S. Army Corps Engr.). 1993. Deep draft navigation reconnaissance report: Cook Inlet, Alaska. Dep. Army, U.S. Army Engr. Dist., Anchorage, 120 p.

[6] Kinney, P. J., J. Groves, and D. K. Button. 1970. Cook Inlet environmental data, R/V *Acona* cruises 065, May 21–28, 1968. Univ. Alaska, Fairbanks, Inst. Mar. Sci., Rep. R-70-2, 122 p.

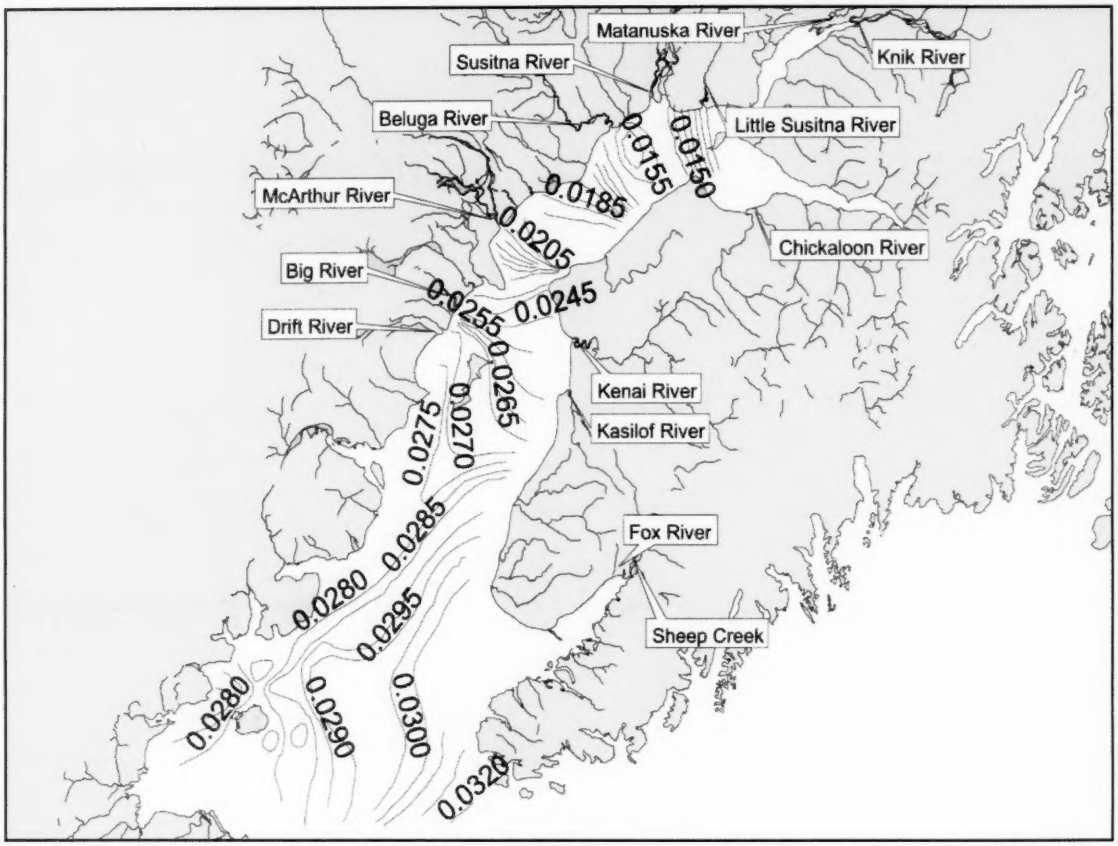

Figure 4.—Major rivers and salinity isohalines of Cook Inlet, Alaska.

are commonly observed east of Kalgin Island, extending south to about Chinitna Bay (Fig. 6) (Burbank, 1977). Tidal bores of up to 3.2 m (10 ft) occur in Turnagain Arm (Region 2). Surface circulation in upper Cook Inlet is driven by the mixing of incoming and outgoing tidewater combined with freshwater inputs (Fig. 6). A southward flow along western lower Cook Inlet is due to the Coriolis Force acting on freshwater entering the upper inlet from rivers.

Current velocities average about 3 kn but are locally influenced by shore configuration, bottom contour, and winds (USACE[5]). For example, currents may exceed 6.5 kn between East and West Forelands, and speeds of up to 12 kn have been reported near Kalgin Island. The tidal flats in upper Cook Inlet provide some protection from the strong currents that predominate in the central inlet. Lower Cook Inlet connects to the GOA through Kennedy and Stevenson Entrances and Shelikof Strait. The ACC flows along the inner shelf in the western GOA and flows northward along the eastern side of Cook Inlet. The relatively fresh turbid upper Cook Inlet outflow meets and mixes with incoming ACC water in the central inlet. This mixture flows along western Cook Inlet and outflows to Shelikof Strait.

Natural Catastrophic Events

Volcanoes

Five volcanoes along the western shore of Cook Inlet have erupted since the Holocene (10,000 years ago). These mountains are, from north to south, Spurr, Redoubt, Illiamna, Augustine, and Douglas. Three of these (Spurr, Redoubt, and Augustine) have erupted more than once during the 20th century (Riehle, 1985; Alaska Geographic, 1991). Floods generated by volcanic ejecta coming into contact with snow and ice on the volcano can impact any drainage on a volcano. Massive debris flows (consisting of several hundred million cubic feet of melted snow and glacial ice combined with sediment) that occurred during the 2 January and 15 February 1990 eruptions of Redoubt Volcano flooded the Drift River valley and damaged logistical support facilities at the Drift River Oil Terminal (Alaska Geographic, 1991). Potential hazards other than flooding are: debris avalanches, mudflows, lava flows, hot gas surges, and ashfall. Dozens of ashfall events were produced by Cook Inlet volcanoes in the

20th century, most of which were a few millimeters or less in thickness (Alaska Geographic, 1991; DNR[7]). The overall effect on fish spawning streams and rivers is not known.

Earthquakes

Active seismic zones beneath Mt. Illiamna, Mt. Douglas, and Mt. Augustine have produced clusters of deep earthquakes ranging from 5 to 6 on the Richter scale (Pulpan and Kienle, 1979). Since 1902, the Cook Inlet area has experienced over 100 earthquakes of magnitude 6 or greater (Hampton, 1982). The second largest earthquake ever recorded, magnitude 9.2 and centered 10 km east of College Fiord in Prince William Sound, resulted in landmass subsidence along much of the east coast of Cook Inlet (Noerenberg, 1971). Subsidence in the Portage area of Turnagain Arm allowed high tides to extend about 2 mi farther upstream resulting in considerable loss of fish spawning habitat (Noerenberg, 1971). Mud deposits and silting covered Pacific salmon, *Oncorhynchus* spp.; trout, *Salmo* spp.; and smelt (Osmeridae), spawning areas along streams on the south side of Turnagain Arm and pink salmon habitat in the Chickaloon River. Minor damage to intertidal spawning streams was observed between the Knik River and Bird Creek. Dewatering and loss of freshwater habitat occurred at Ship Creek near Anchorage which stopped flowing for 18 h and farther south in Cook Inlet at the Kasilof River which slowed to a trickle. The Susitna River experienced landslides but tributaries and streams were not blocked. Some loss of intertidal Pacific salmon spawning habitat also occurred in streams in Kachemak Bay.

Fires

Fire statistics for 1990 through 1998 for the Anchorage/Matanuska-Susitna (Anc/Mat-Su) region and the Kenai/Kodiak region are summarized in Table 1. The largest fires, in terms of acres burned, occurred adjacent to both the upper (Anc/Mat-Su) and lower (Kenai/Kodiak) portions of Cook Inlet in 1996. Only 3 incidents of fire were reported in the Cook Inlet Keeper (CIK[8]) database which contains information from 1990 through 1997. Fires that occur in watersheds can cause increased runoff. Debris from this runoff could cover gravel spawning beds of salmon. Decreased shading along stream banks resulting from fire may expose adult salmon to greater numbers of predators. Overall, the ramifications of fire may cause decreased Pacific salmon numbers in the short term.

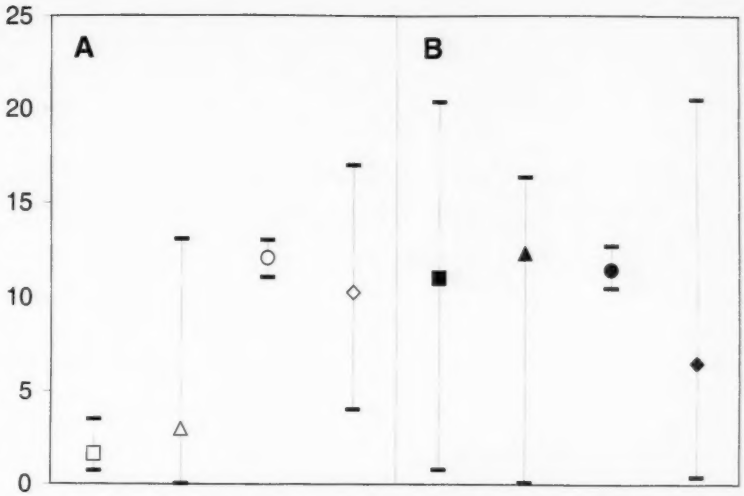

Figure 5.—Comparison of results from hydrographic sampling of nearshore areas occupied by belugas (A: open symbols) to offshore sites (B: closed symbols). Error bars indicate minimum and maximum readings for water depth (m) (squares), salinity (ppt) (triangles), temperature (°C) (circles), and turbidity (mg/l × 10) (diamonds).

Table 1.—Summary of fire statistics for the Anchorage/Matanuska-Susitna and the Kenai/Kodiak regions. Source: State of Alaska, Division of Forestry website [http://www.dnr.state.ak.us/forestry/] accessed 12 February 2000.

	Anc/Mat-Su Region		Kenai/Kodiak Region	
Year	No. of fires	Acres burned	No. of fires	Acres burned
1990	96	55.0	55	135.0
1991	116	1,267.4	47	7,930.1
1992	111	155.3	94	205.0
1993	121	164.7	94	42.5
1994	95	36.2	69	3,818.0
1995	90	163.1	50	411.8
1996	186	37,781.0	101	28,219.7
1997	149	155.9	80	14,246.5
1998	77	52.9	33	19.3

Ice Cover

Sea ice generally forms in October–November, reaches its maximum extent in February (generally from West Foreland to Cape Douglas), then recedes and melts in March–April (Fig. 7) (Mulherin et al., 2001). Ice formation in upper Cook Inlet is driven by air temperature, while the air/water temperature and inflow rate of the ACC influence sea-ice formation in the lower inlet (Poole and Hufford, 1982). Tidal action and tidal currents often shatter sea ice

[7] DNR. 1999. Cook Inlet areawide 1999 oil and gas lease sale: final finding of the director, vol. I. Alaska Dep. Nat. Resour., Div. Oil Gas, Anchorage, v.p.

[8] The Cook Inlet GIS Atlas with annotated bibliography and watershed directory is available on CD from Cook Inlet Keeper, P.O. Box 3269, Homer, AK 99603 [e-mail: keeper@xyz.net or website: www.xyz.net/~keeper].

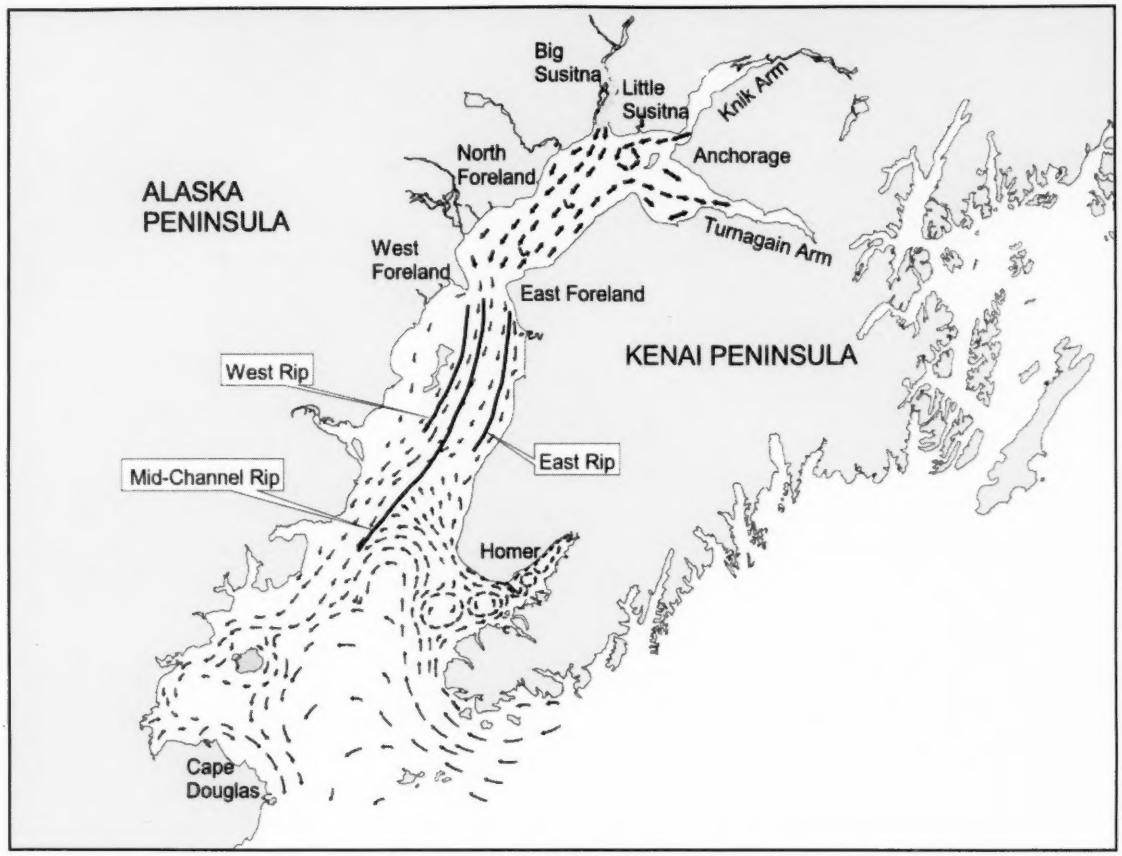

Figure 6.—Surface circulation including tidal rips in Cook Inlet, Alaska.

in Cook Inlet to the extent that there is seldom uniform cover.

Potential Effects on Belugas

There are no clear correlations between any single physical factor and beluga distribution in Cook Inlet. Tides and resulting water depths and temperature may influence beluga distribution near the river deltas. Much of the literature on belugas and their use of coastal estuaries focuses on the movement of these animals relative to tides (summarized in Kleinenberg et al., 1964). Where water levels fluctuate markedly, inshore migrations primarily occur during high tide. In Russian waters, belugas migrate along the shore during the high spring tides (Kleinenberg et al., 1964), with movement into rivers driven by prey availability (see section on Prey Variability). In Canadian waters (i.e. Nastapoka Estuary), herd position was also found to correlate with tide (Caron and Smith, 1990). Beluga groups moved into the upper reaches of the estuary during flood tide and departed during ebb tide. Similar movement patterns have been observed in Cook Inlet. Traditional knowledge and beluga whale hunting techniques suggest that these patterns have changed little since prehistoric times (Huntington, 2000; Mahoney and Shelden, 2000).

The temperature range in Cook Inlet is similar to that reported for other estuaries used by belugas. For example, beluga studies conducted in Canadian estuaries reported water temperatures from 10° to 18°C, while surrounding waters registered from 0° to 7°C (Finley et al., 1982; Hansen, 1987). While belugas in Cook Inlet appear to favor warm, turbid, low-salinity waters in summer, studies in other areas suggest that belugas are as likely to be found in clear water estuaries as in turbid habitats (Bel'kovich and Shchekotov, 1990; Caron and Smith, 1990; Smith et al., 1994). However, clear water estuaries in the lower inlet (such as Kachemak Bay) are now rarely occupied by belugas during the summer months (Rugh et al., 2000). One study conducted in the Churchill River estuary of Hudson Bay, Canada, found no significant correlation between beluga abundance and turbidity; however, water temperature affected both beluga abundance and distribution (Hansen, 1987).

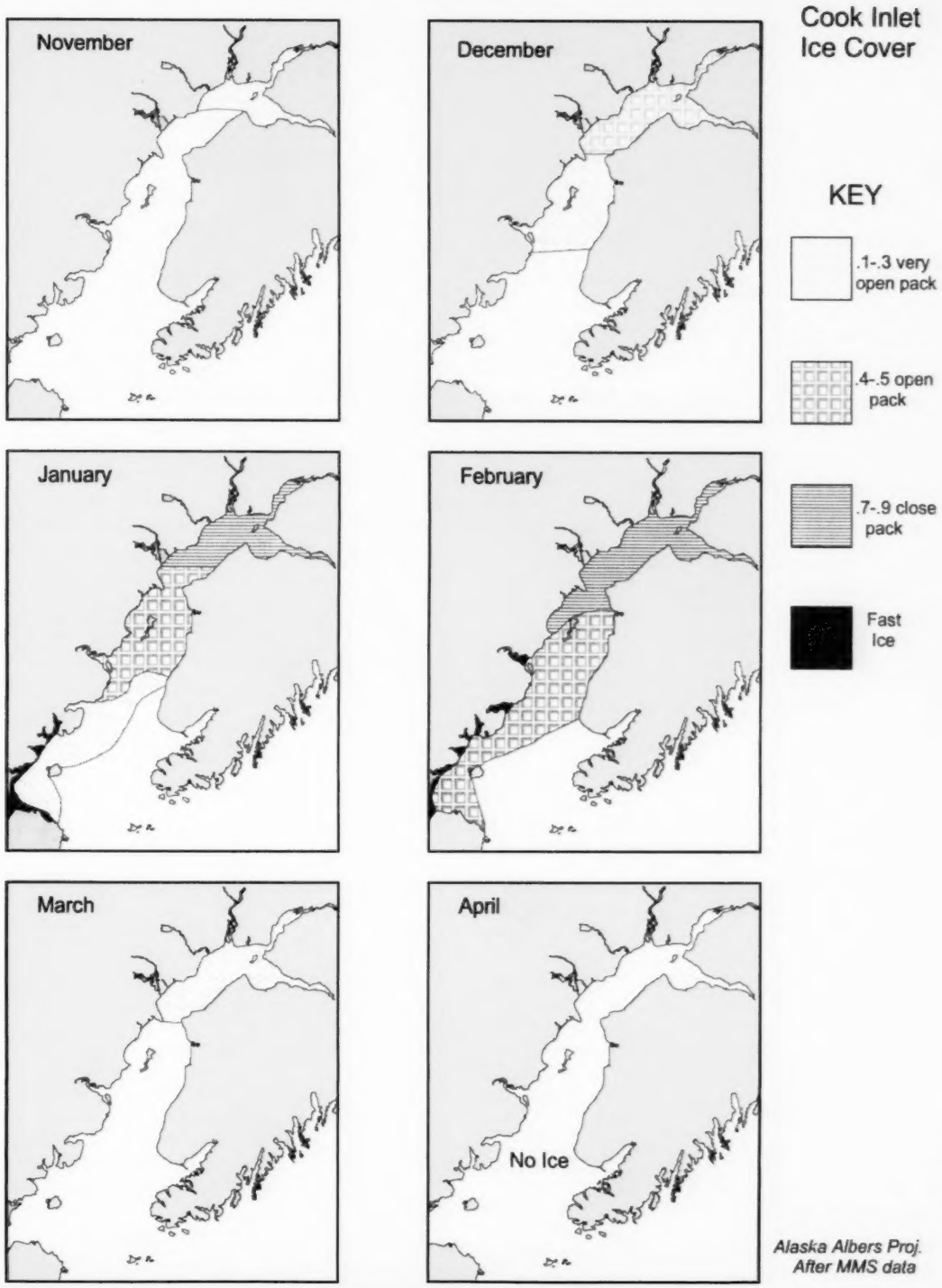

Figure 7.—Seasonal extent of sea ice in Cook Inlet, Alaska (from MMS[20]).

The blubber layer of newborn belugas can be ten times thinner than that of an adult (Kleinenberg et al., 1964). Adults with calves are present in Cook Inlet during summer and it is possible that the warmer water reduces thermal stress to newborns (Hansen, 1987), and facilitates the molt of the thick, horny layer of skin they are born with (Watts et al., 1991). Warmer water may also provide a thermal advantage to adults undergoing seasonal molt (Watts et al., 1991). Yellowing skin is a characteristic of this epidermal molt (St. Aubin et al., 1990), and Alaska Natives in Cook Inlet reported that old belugas are yellow (Huntington, 2000). As belugas enter warmer water, epidermal growth is stimulated and older, rough skin is shed. Thus water temperature, and by association salinity, may play a role in habitat selection of belugas during summer months.

In northern Cook Inlet, belugas have been seen in open leads and in 40–60% ice cover in winter (Hansen and Hubbard, 1999), suggesting that ice cover is not a limiting factor to their distribution. From habitat associations in the Beaufort Sea (Moore, 2000; Moore et al., 2000) and elsewhere, it is clear that belugas are an ice-adapted species capable of transiting vast areas nearly covered by sea ice (e.g. Suydam et al., 2000).

As discussed in the next section, occupation of coastal areas, particularly near river mouths, seems more likely driven by prey availability than specific hydrographic conditions. Elsewhere, large beluga herds have been reported associated with large prey aggregations in comparatively small feeding areas (Bel'kovich, 1960; Welch et al., 1993). Thus, in Cook Inlet, physical factors may influence beluga assemblages indirectly by affecting the distribution of prey, or directly only in terms of tides, currents and resultant water depth and temperature.

Biological Factors

Prey Species and Availability

Although the diet of belugas in Cook Inlet is largely unknown, elsewhere belugas prey on a wide variety of fish, crustaceans, and cephalopods (Seaman et al., 1982). Cook Inlet is host to a wide range of fish species, including year-round residents and many anadromous species that return seasonally to spawn in rivers. Alaska Natives have expressed concern over reports of declining fish runs and the potential negative impact this may have on the Cook Inlet beluga population (Huntington, 2000). However, determining the prey available to belugas is a complex task that has yet to be accomplished, both because fish run data are assimilated for purposes unrelated to beluga research and because not all potential prey species are counted. The data available for review tell an equivocal story.

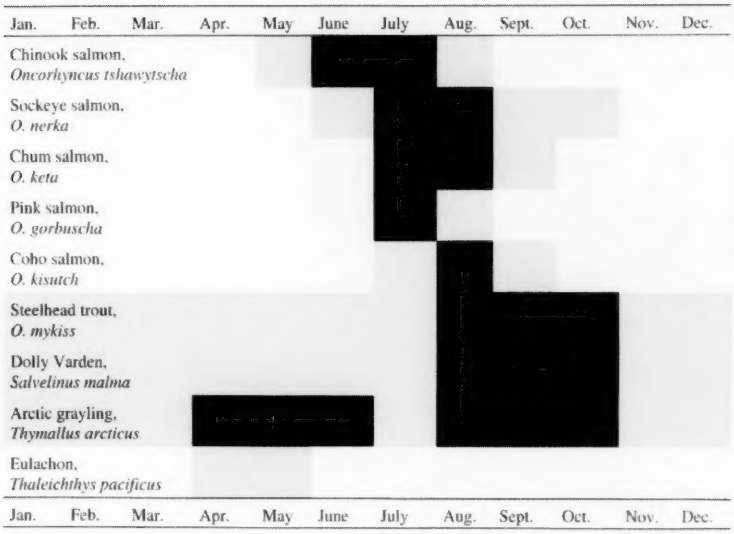

Figure 8.—Approximate timing of the presence (gray shading) and peak availability (black shading) of fish species entering fresh water drainages in upper Cook Inlet (from AOJ[9]).

The fish fauna of upper Cook Inlet is primarily characterized by the spring to fall availability of migratory eulachon, *Thaleichthys pacificus*, outmigrating Pacific salmon smolt, and returning adult Pacific salmon (Fig. 8, also see AOJ[9]). Moulton (1997) documented 18 fish species in upper Cook Inlet (Table 2) and noted that species abundance and distribution vary greatly throughout the summer. Since 1990, commercial fisheries for sockeye salmon, as well as sport fisheries for chinook and coho salmon, have reported declines in a number of fish runs in upper Cook Inlet (Rutz and Sweet, 2000; ADFG[10]). Interannual fluctuations in escapement counts for coho, pink, chum, and sock-

Table 2.—Fish species found in upper Cook Inlet, Alaska, June–September 1993 (Moulton, 1997). Species are listed from most to least abundant based on catch data.

Common name	Scientific name
Threespine stickleback	*Gasterosteus aculeatus*
Pacific herring	*Clupea pallasi*
Pink (humpback) salmon	*Oncorhynchus gorbuscha*
Eulachon (candlefish, hooligan)	*Thaleichthys pacificus*
Chum (dog) salmon	*Oncorhynchus keta*
Walleye pollock	*Theragra chalcogramma*
Longfin smelt	*Spirinchus thaleichthys*
Saffron cod	*Eleginus gracilis*
Chinook (king) salmon	*Oncorhynchus tshawytscha*
Sockeye (red) salmon	*Oncorhynchus nerka*
Coho (silver) salmon	*Oncorhynchus kisutch*
Arctic lamprey	*Lampetra japonica*
Pacific sandfish	*Trichodon trichodon*
Pacific sand lance	*Ammodytes hexapterus*
Snake prickleback	*Lumpenus sagitta*
Capelin	*Mallotus villosus*
Starry flounder	*Platichthys stellatus*
Ninespine stickleback	*Pungitius pungitius*

[9] Data on fish run timing obtained from the Alaska Outdoor Journal (AOJ) website [http://www.alaskaoutdoorjournal.com/References/matsutime.html] and the Alaska Dep. Fish and Game website [http://www.state.ak.us/adfg/sportf/geninfo/runtim/runtim.htm], 26 February 1999.

[10] Data obtained from Alaska Dep. of Fish and Game websites for commercial fisheries [http://www.cf.adfg.state.ak.us/region2/ucihome.htm] and sport fisheries [http://www.state.ak.us/adfg/sportf/region2/projnci.htm], 4 November 1999.

eye salmon at the Yentna River and chinook at the Deshka River of the Susitna River drainage occurred between 1993 and 1998 (Fig. 9). However, on a decadal scale there appeared to be no overall change in sockeye escapements (Fig. 10a) for the Susitna River drainage, though chinook (Fig. 10a), pink (Fig. 10b), and chum salmon (Fig. 10c) appeared to decline, and coho appeared to increase (Fig. 10c) from the 1980's to the 1990's.

These data are difficult to interpret with reference to prey available to belugas, both because changes in commercial and sport fishing patterns may be masking trends in salmon escapement, and the status of salmon stocks is so variable from drainage to drainage. In addition, some of the recent salmon stock declines may be due to flood-related mortality, northern pike, *Esox lucius*, predation on juvenile salmon, and poaching (Rutz and Sweet, 2000). Additional concerns for salmon stocks in the upper inlet include: urbanization, stream bank erosion caused by foot traffic and power boats, litter accumulation, and proposed timber sales and logging activity near juvenile salmon rearing habitat (Rutz and Sweet, 2000).

Lower Cook Inlet supports a diverse fish community, with 50 different species identified in Kachemak Bay and 24 species for waters near Chisik Island (Robards et al., 1999). Notably, the Kachemak Bay fish community changed significantly between 1976 and 1996 (Robards et al., 1999), coincident with a large-scale climate change (also called regime shift) in the North Pacific in the late 1970's (Francis et al., 1998; Anderson and Piatt, 1999). There has been a noticeable decline in marine species in this region resulting in the closure of commercial fisheries for shrimp, *Pandalus* sp., and king crab, *Paralithodes camtschatica,* and artificial enhancement of Pacific salmon runs (Alaska Geographic, 1994; Bechtol, 1997; Kruse, 1998), while other species such as walleye pollock, *Theragra chalcogramma*, have dramatically increased (Bechtol, 1997).

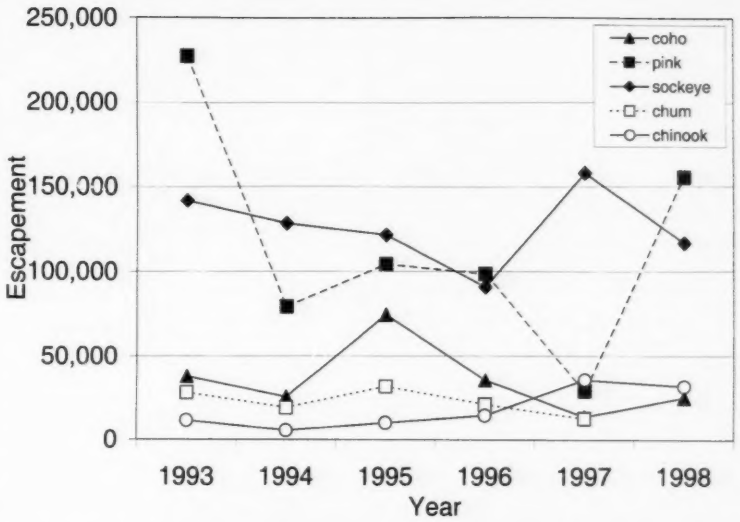

Figure 9.—Annual salmon escapement for the Yentna (coho (▲), pink (■), sockeye (◆), and chum (□)) and Deshka Rivers (chinook (○)), 1993–98 (from Davis (1998) and Fried (1999)). These rivers are main tributaries of the Susitna River complex. Yentna counts were obtained using side-scanning sonar and Deshka counts were obtained using aerial surveys and weirs.

Predators

Killer whales, *Orcinus orca,* sometimes prey on belugas in Cook Inlet, although the extent of predation is unknown (Morris[11]). There are only four confirmed (and one unconfirmed) reports of killer whales in upper Cook Inlet since 1988, although these opportunistic sightings probably underrepresent actual killer whale occurrence. In May 1991, a pod of six killer whales (2 males, 3 females, 1 juvenile) were stranded at low tide near Girdwood in Turnagain Arm (NMFS[12]). On 20 June of that same year, a dead beluga was found with teeth marks and a piece of its tail missing (Table 3). In August 1993, a pod of five killer whales, including a male that later died, stranded at Bird Point, Turnagain Arm. This male regurgitated beluga whale parts before dying (NMFS unpubl. data). In June 1994, there was an unconfirmed report of "killer whales in the area" when a group of roughly 190 belugas stranded during a low tide at the mouth of the Susitna River (Table 3). On 29 August 1999 at least three killer whales were seen chasing belugas just south of Bird Point roughly 2 h before about 60 belugas stranded there (NMFS unpubl. data). In late September 2000, 3–5 killer whales were seen near Bird Point and at Peterson Creek in Turnagain Arm. They killed (but did not eat) at least two lactating belugas and may have consumed their calves. Frequent sightings of killer whales in lower Cook Inlet, in Shelikof Strait, and along the south side of the Kenai Peninsula to Prince William Sound (Dahlheim, 1997) suggest the potential for predation there may be somewhat higher.

Natural Mortality

Stranding records for belugas in Cook Inlet include animals that presumably died of natural causes and those that were released alive on the incoming tide (Table 3), as well as animals taken by Alaska Native hunters (Mahoney and Shelden, 2000). The stranding reports are opportunistic and therefore do not necessarily represent the actual number of occurrences.

Belugas sometimes strand during low tide cycles in upper Cook Inlet, possibly

[11] Morris, B. F. 1988. Cook Inlet beluga whales. Unpubl. rep. on file at NMFS Alaska Reg. Off., Anchorage, 34 p.

[12] NMFS. 1992. Status report on Cook Inlet belugas (*Delphinapterus leucas*). Unpubl. rep., 22 p., on file at Alaska Reg. Off., Natl. Mar. Fish. Serv., 222 W. 7th Ave. #43, Anchorage, AK 99513.

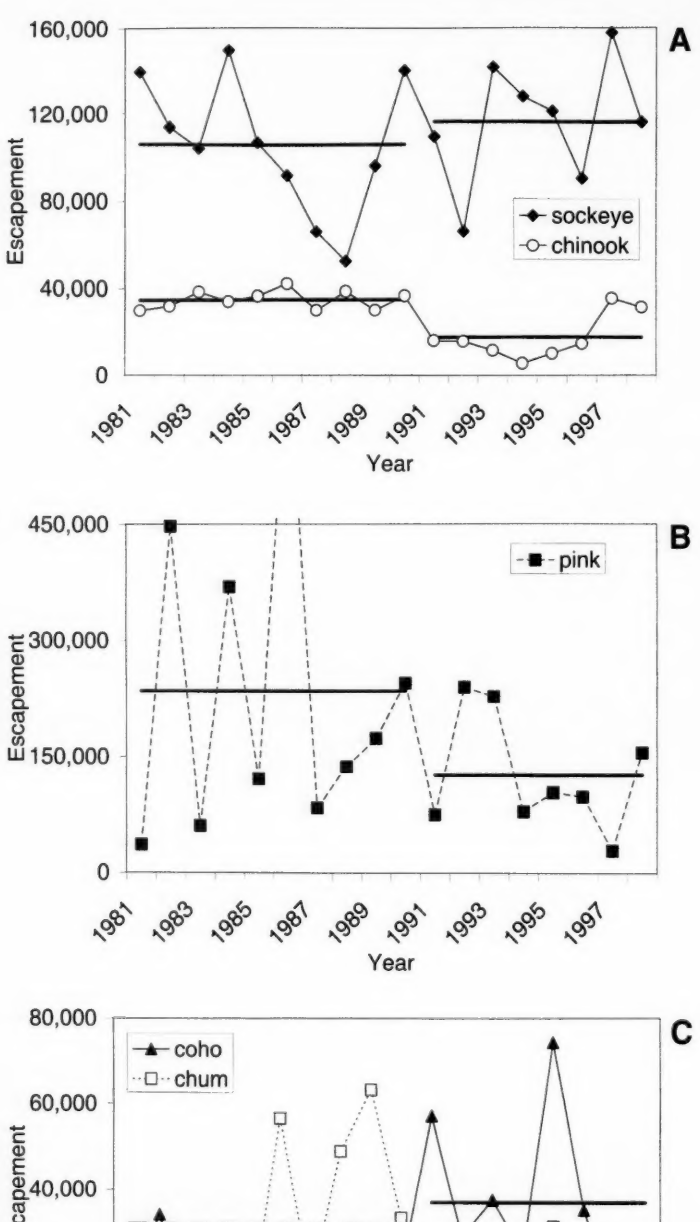

Figure 10.—Annual escapement of: a) sockeye (◆) and chinook (○), b) pink (■), and c) coho (▲) and chum (□) salmon for tributaries of the Susitna River, 1981–98 (Davis, 1998; Fried, 1999). Sockeye, pink, coho, and chum counts were obtained using side-scanning sonar and chinook counts were obtained using aerial surveys and weirs.

while avoiding predators or when following prey upriver. Most strandings are of single whales, although live groups of 10–190 individuals have been reported (Table 3). There is no evidence that strandings are the result of viral or parasitic infections. However, in a few cases deaths have occurred, possibly from the stress of stranding in combination with such an infection (Table 3; Burek-Huntington[13]). While most strandings do not result in mortality, it is important to note that there is the potential for a single event to result in the death of a significant proportion of this relatively small stock.

Potential Effects on Belugas

Prey availability likely has the strongest influence on the distribution and relative abundance of belugas in Cook Inlet. The patterns and timing of eulachon and salmon runs seems to affect beluga feeding behavior. Belugas routinely group near the Susitna River Delta in early summer (Rugh et al., 2000). Alaska Natives report that the whales feed there on migrating fish, predominantly eulachon and salmon (Huntington, 2000), which have been identified in stomach contents of harvested whales (NMFS unpubl. data). Feeding strategies are similar to those displayed in other regions. In environments equivalent to the Susitna Delta, belugas hunting salmon formed large compact groups ranging from tens to hundreds of individuals (Bel'kovitch and Shchekotov, 1990). Such group formations have been observed in the east and west tributaries of the Susitna River and in the mouths of the Little Susitna River and the Beluga River (Rugh et al., 2000).

[13] Burek-Huntington, K. 2000. Summary of lesions from beluga whale cases submitted to AVPS [Alaska Veterinary Pathology Services] in 1998 and 1999. Unpubl. rep. for Alaska Reg. Off., Natl. Mar. Fish. Serv., 222 W. 7th Ave. #43, Anchorage, AK 99513, 6 p.

Table 3.—Summary of beluga whale strandings in Cook Inlet, Alaska 1988-2000 (does not include animals killed during subsistence harvests). Animals were alive at time of stranding unless noted otherwise.

Date	Vital statistics	Location
1988		
23 Oct.	Group of 27 comprised of 3 calves, 4 yearlings, 20 adults. Released with the incoming tide.	Turnagain Arm, Girdwood.
1989		
1 Sept.	Dead female, length 360 cm.	Anchorage, Earthquake Park.
12 Sept.	Dead male, length 425 cm.	Anchorage, Campbell Creek.
1990		
18 May	Dead whale, unidentified sex, length 8′10″. Knife marks.	Anchorage, Point Woronzof.
15 June	Dead whale, unidentified sex, length ~12′.	Shirleyville.
1991		
20 June	Dead whale, unidentified sex, length 6′-6.5′. A chunk of the tail missing, orca teeth marks evident.	Turnagain Arm, MP 110.5 on Seward Highway.
31 Aug.	Group of 70-80 whales. Released with the incoming tide.	Turnagain Arm, near Twentymile.
1992		
2 June	Skeleton.	Little Susitna River.
2 Sept.	Dead male, length 14′2″.	Turnagain Arm, Potters Marsh.
6 Oct.	2 dead males, lengths 150″ and 162″. Both found sick and dying.	Kenai River, ~2 miles north.
1993		
6 July	Two groups comprised of 5 and 5+ whales. Released with the incoming tide.	Hope, MP 13 on Hope Road.
1994		
5 June	Dead female, length 348 cm.	Anchorage, ~2 miles north of Campbell Creek.
14 June	Group of ~190 released with the incoming tide. Reports of killer whales in the area.	Susitna River mouth.
10 Aug.	Dead male, length 14′8″.	Little Susitna River mouth.
19 Aug.	Skeleton.	Ivan River, north.
13 Sept.	Dead male, length 364 cm (headless).	Turnagain Arm, Bayshore.
15 Sept.	Dead male, length 474 cm.	Knik Arm, Birchwood.
23 Sept.	No data.	Nikiski, Unocal dock.
12 Oct.	Dead male, length 478 cm.	Kalifornsky Beach, Kasilof River
1995		
21 July	Dead female, length 293 cm.	Kenai River, ~ 2 miles north.
14 Aug.	No data.	Shirleyville.
13 Sept.	Dead female, length ~120″. No flukes.	Eagle River Flats, south.
31 Oct.	Grayish-white.	Nikiski, OSK Dock.
1996		
12 June	Group of 63 comprised of 24 gray and 39 white whales. Released with the incoming tide.	Susitna River, East Fork.
13 July	No data.	Little Susitna River, ~2 mi. west.
1 Aug.	Dead whale, unidentified sex, length 144″.	Susitna River, ~1 km south.
2 Aug.	Dead male, length 412 cm. Wound on dorsal.	Turnagain Arm, Bayshore.
13 Aug.	Dead whale, unidentified sex, length 155 cm.	Turnagain Arm, MP 2.3 on Coastal Trail.
28 Aug.	Group of 60 released with the incoming tide. Four dead whales included 2 males, lengths 376 cm and 438 cm, and 2 females, lengths 410 cm and 413 cm.	Turnagain Arm, Bird Point.
2 Sept.	Group of 20-30 released with the incoming tide, 1 died.	Turnagain Arm, north of Bird Point.
8 Sept.	Released with the incoming tide.	Knik Arm, ~MP 14 on Knik-Goose Bay Road.
19 Sept.	Dead whale, unidentified sex, length 144″.	Kenai, Salamantof Beach.
2 Oct.	Group of 10-20 released with the incoming tide.	Turnagain Arm, Indian Creek.
24 Oct.	Dead whale, unidentified sex, length 364 cm.	Anchorage, Ship Creek.
25 Oct.	Skeleton. Length ~150″.	Anchor Point.
1997		
? June	No data.	Anchorage boat ramp.
4 June	Dead female, length 350 cm.	Turnagain Arm, Bayshore.
27 Aug.	No data.	Anchorage city dock.
1998		
9 Apr.	Dead male, length 254 cm, ~2 years old. Pneumonia was diagnosed.	Turnagain Arm, ~3 miles south of Girdwood.
14 May	Group of 30 comprised of ~12 gray and 18 white whales. Released with incoming tide.	Turnagain Arm, ~6 miles east of Hope.
22 May	Dead male, length 14′4″.	Susitna River, East Fork.
8 June	No data.	Ninilchik, ~4 miles offshore.
13 June	No data.	Cook Inlet, off Chinitna Bay.
15 June	No data.	Lewis River
16 June	No data.	Susitna River, Big Island.
28 July	Dead male, length 11′2″. Total reported strandings for entire Island was 6 from April through July.	Fire Island, NE.
11 Aug.	Dead male, length 11′8″.	Fire Island, SW.
7 Sept.	Group of 5 whales. Released with incoming tide.	Turnagain Arm, between Hope and Beluga Point.
9 Sept.	Dead male, length 366 cm.	Turnagain Arm, Placer River.

Continued on next page.

Table 3.—Continued.

Date	Vital statistics	Location
1999		
7 July	Dead whale, unidentified sex, 191 cm.	Chuitna River, Tyonek
15 July	Dead calves (2), unidentified sex.	Fire Island, W.
26 July	Dead calf (no teeth in jawbone), unidentified sex.	Fire Island, Race Point.
25 Aug.	Dead whale, unidentified sex.	Knik Arm, Settlers Bay.
29 Aug.	Group of about 60 whales released with incoming tide. About 5 died. Killer whales seen chasing belugas 2 h prior to stranding.	Turnagain Arm, MP 100.
9 Sept.	Group of 12–13 whales released with incoming tide.	Rainbow, near Seward Hwy.
11 Sept.	Dead whale, very decomposed, 135 cm.	Turnagain Arm, near Shore Dr.
18 Sept.	Dead whale, very decomposed, 150 cm.	Turnagain Arm, N.
2000		
early April	Skeleton.	Ninilchik.
29 May	Dead whale, unidentified sex, gray color.	Point Possession.
4 June	Dead whale, unidentified sex, length 10′.	Point Possession, N. Miller Creek.
12 June	Dead male, length 437 cm.	Point Possession.
19 June	Dead male, length 242 cm.	Point Possession, Coast Guard Light.
24 June	Dead male, length 335 cm.	Knik Arm, Port of Anchorage.
23 July	Dead male, length 67 in.	Turnagain Arm, Point Campbell.
24 July	No data.	Little Susitna River, halfway between the mouth and powerlines.
11 Aug.	Dead whale, unidentified sex, length 172 cm.	Chuitna River.
27 Aug.	Group of 8 comprised of 7 adults and 1 calf. Released with incoming tide.	Turnagain Arm, 5 mi. E. of Beluga Point
1st week Sept.	Dead whale, unidentified sex. Chunks of blubber and meat missing from belly, possible orca teeth marks.	Nikiski, Unocal loading dock.
17 Sept.	Dead female, young, length 180 cm, 200 lbs.	Turnagain Arm, Peterson Creek.
25 Sept.	Dead female, lactating, length 375 cm. Orca predation.	Turnagain Arm, Indian Creek.
26 Sept.	Dead female, lactating, length 364 cm. Orca predation.	Turnagain Arm, Bird Creek.
24 Oct.	Group of 2 whales released with incoming tide.	Turnagain Arm, McCue Creek

Dispersal of the large groups of whales is usually not observed until later in the summer (Rugh et al., 2000; Calkins[1]). Dense concentrations of salmon and eulachon in early June, followed by the availability of more dispersed species later in the summer (Moulton, 1997), may account for this change in beluga group size and composition. The paucity of beluga sightings in lower Cook Inlet in the 1990's (Rugh et al., 2000) relative to the 1970's (Calkins[1]) leads to speculation that belugas no longer find preferred prey in the lower inlet (Speckman and Piatt, 2000). However, the impact on Cook Inlet belugas of a changing fish community may be difficult to quantify because the beluga diet is flexible and changes with season, location, sex, and age (Seaman et al., 1982; Stewart and Stewart, 1989).

To date, there has been no coordination between biologists counting fish runs (and thereby estimating the availability of some beluga prey) and those conducting surveys for belugas in Cook Inlet. Fish run counts are conducted to answer fishery-related questions, which limits the interpretation of available data regarding the influence of prey availability on beluga occurrence. Coordinated research is needed to correlate beluga occurrence and distribution to prey availability. The majority of beluga stranding events likely result from pursuing prey into the shallows in the upper inlet, while a few may occur when belugas attempt to evade killer whales or other potential threats (Huntington, 2000) or when a whale is ill.

Anthropogenic Factors

Fishing

The Cook Inlet area supports recreational, commercial, subsistence, and personal use fisheries (ADFG[14]). All of these fisheries are subject to regulations under Title 5 of the Alaska Administrative Code. In Cook Inlet, recreational fishing generally occurs within river drainages and is usually limited to unbaited, single hook or artificial lures depending on location and species fished. Commercial fishing occurs in Region 1 and 2 (Fig. 1) north of the Forelands in upper Cook Inlet (the Northern District commercial fishery), in Region 2 and 3 in the central inlet between the Forelands and Anchor Point (the Central District), and in Region 2 and 3 in the Kamishak Bay District (waters west of long. 152°20.00′ W and north of Cape Douglas) and the Southern District (waters east of long. 152°20.00′ W and north of Elizabeth Island).

The Northern District is made up of 5 individual set gillnet fisheries while the Central District includes both set gillnet and drift net fisheries (Fig. 11). The Southern and Kamishak Bay Districts allow the use of purse seines, hand purse seines, and beach seines. Set gillnets can also be used in the Southern District in specific locations along the south shore of Kachemak Bay between Halibut Cove and Port Graham. All four districts allow the use of groundfish gear (including pelagic trawls, hand troll gear, longlines, pots, and mechanical jigging machines) but regulate gear type by location and species fished.

Subsistence fishermen may harvest finfish (other than Pacific salmon, and rainbow and steelhead trout, *Oncorhynchus mykiss*) at any time in any area of the state by any method unless restricted by the subsistence fishing regulations under Title 5. Cook Inlet fishing seasons

[14] Data obtained from the Alaska Dep. Fish Game website, 25 August 2000 [http://www.cf.adfg.state.ak.us/].

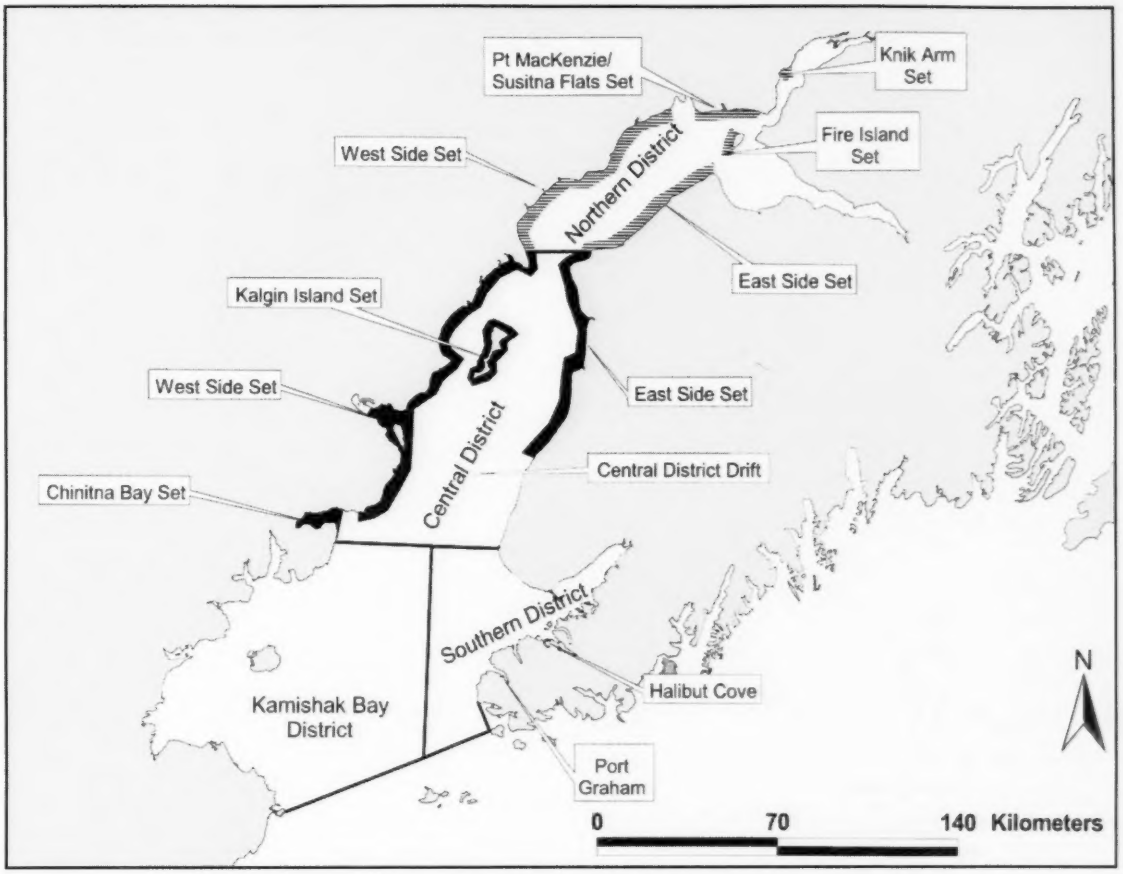

Figure 11.—Cook Inlet commercial fishing districts and individual set and drift net fisheries.

start at varying times by region (generally sometime in June) and continue until closed by an emergency order.

Oil and Gas Activities

There are seven oil producing fields supporting 15 oil and gas offshore platforms in upper Cook Inlet in Region 3 (Fig. 12). Underwater noise, habitat loss, and oil spills are generally cited as the foremost potential negative impacts of petroleum development activities on marine mammals (Geraci and St. Aubin, 1990). In 1999, the Alaska Department of Natural Resources (DNR), Division of Oil and Gas, proposed 815 tracts for lease in Cook Inlet (DNR[7]). Habitat loss due to oil and gas development was assumed by DNR to be limited to temporary displacement of harbor seals, *Phoca vitulina*, and sea otters, *Enhydra lutris*, from haulouts and nearshore foraging areas during construction of pipelines and transport facilities in Cook Inlet (DNR[7]). The possibility of disturbing and displacing belugas from similar nearshore habitats during these activities was not discussed. Although habitat loss may occur only temporarily during construction, a natural gas blowout or oil spill in upper Cook Inlet could put the beluga population at great risk.

Cook Inlet offshore oil platform spills totaled approximately 10,500 gal between 1984 and 1994 (DNR[7]). Four natural gas blowouts have occurred in Cook Inlet since 1962. The last gas blowout lasted from December 1987 until June 1988 at the Steelhead Platform well, M-26, on the McArthur River Field where escaping gas ignited, damaging the platform and injuring workers (DNR[7]). Offshore pipeline failures have not been reported since 1976. In 1987, the tanker *Glacier Bay* spilled about 210,000 gal of crude oil, interrupting commercial fishing operations near Kalgin Island during the peak of the sockeye salmon run (DNR[7]). Less than 10% of the oil was recovered. Smaller oil spills have occurred at the Drift River and Nikiski marine terminals in Cook Inlet. When ice forced the Unocal tanker *Coast Range* away from the Drift River facility dock in December 1990, about 630 gal spilled from the dock pipe (DNR[7]). Booms and skim-

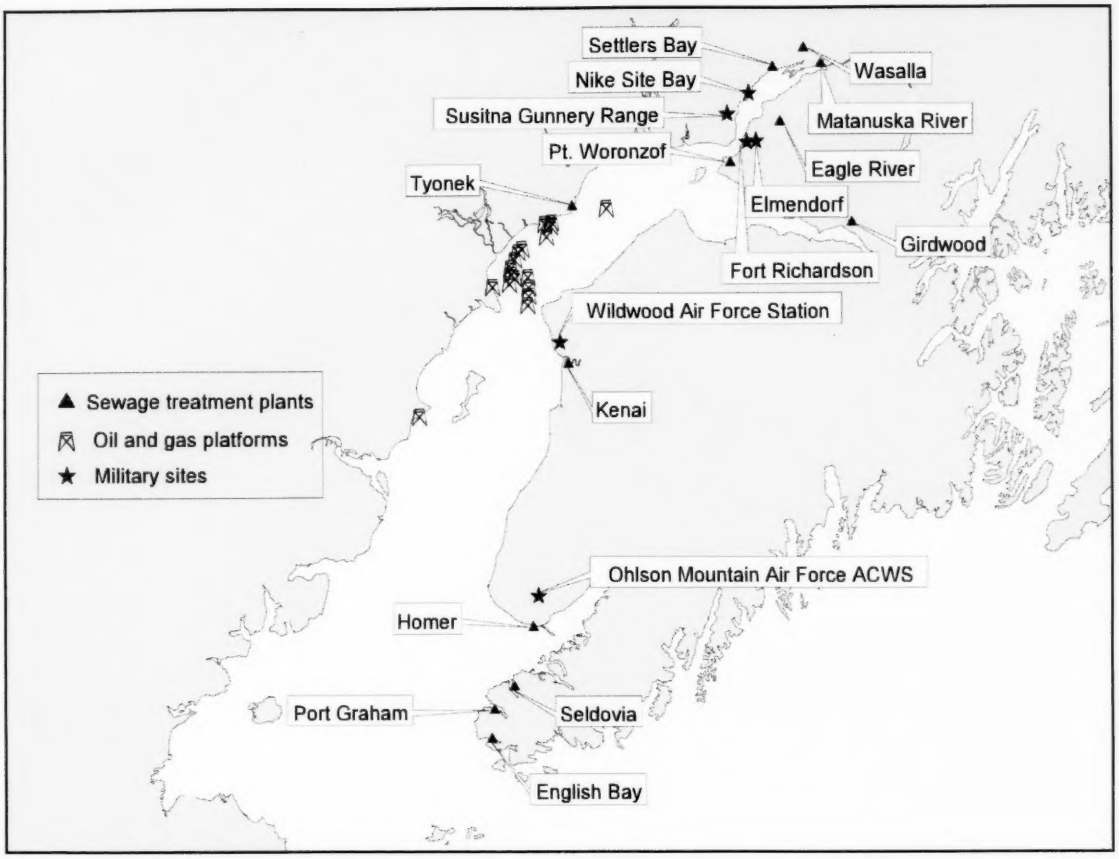

Figure 12.—Oil and gas platforms, sewage treatment facilities, and military sites of Cook Inlet, Alaska.

mers were ineffective in the heavy ice and about 300 gal could not be recovered. On 5 December 1995, between 2,500 and 2,900 gal of crude oil were released into Cook Inlet when an overflow alarm failed at Nikiski (DNR[7]). The oil traveled north into the rip currents and disappeared from view within three days.

Cetaceans are very mobile and are able to detect oil, however, they do not appear to avoid spills (Geraci, 1990). The greatest potential hazard associated with spills are the highly toxic vapors that concentrate above oil slicks and can result in sudden death if inhaled (Geraci, 1990). This phenomenon may have contributed to the loss of killer whales from AB pod during the *Exxon Valdez* spill in Prince William Sound (Harvey and Dahlheim, 1994). Several oil-spill trajectory models have been developed for Cook Inlet, however, these models have not yet been validated by more extensive direct measurements of currents, tidal rips, and water chemistry (Johnson and Okkonen, 1999).

Transportation

Vessel Traffic

Cook Inlet experiences very high volumes of vessel traffic relative to most of Alaska because the Port of Anchorage is an important distribution and transportation hub. This traffic affects parts of Regions 1, 2, and 3. Deep draft containerships and liquid-bulk petroleum vessels represent the majority of vessels berthing at the Port of Anchorage. For example, in 1992, 640 ships docked at the Port of Anchorage[15]: 319 were cargo vessels, 214 were deep-water freighters, 15 were petroleum tankers, and 92 were barges (76 of which were oil carriers). No cruise ships docked, compared to 4 port calls in 1991. There are no commercial vessel-based beluga whale-watching activities currently operating in Cook Inlet.

Vessel traffic in the upper inlet could change dramatically if plans to develop the Point MacKenzie Port in lower Knik Arm across from the Port of Anchorage are ever realized. Point MacKenzie is currently a barge port, but long range

[15] Port of Anchorage. 1992. Port of Anchorage yearly vessel arrival report for 1992. Municipality of Anchorage, Anchorage, Alaska.

plans include dredging to support a bulk loading facility for export of resources such as coal, wood chips, and logs. Commuter ferry service between Anchorage and Point MacKenzie Port has also been discussed, but recent concerns about the stability of the Point MacKenzie dock undermine the likelihood of this development in the near future (Komarnitsky[16])

Tankers must maintain a minimum distance of 5 mi from shore when transiting through Cook Inlet. Marine pilots are assigned to vessels navigating within Cook Inlet and docking at the Port of Anchorage. A deep-water Anchorage area in Kachemak Bay can accommodate up to three vessels when scheduling conflicts or weather delays occur. Since 1965, the Anchorage Harbor has been dredged to a depth of about 10 m (35 ft) below mean lower low water to accommodate deep draft vessels. Shoal movement along Fire Island and off Point Woronzof resulted in the initiation of dredging operations on the Knik Shoal in the late 1990's. Concerns expressed by environmental groups over impacts from dredging vessels operating off Fire Island have led to development of a monitoring program by the USACE (McConnell[17]).

Aircraft Overflights

Cook Inlet experiences significant aircraft traffic throughout the year. In 1998, over 40% of general aviation aircraft operating in Alaska were based in Anchorage (3,892 of 9,825) as well as 47% of licensed pilots (4,365 of 9,246) (MOA[18]). On average, 166 commercial passenger and 93 cargo planes land daily at Anchorage International Airport (Goldsmith[19]), as well as numerous private aircraft. Seaplane traffic in upper Cook Inlet is primarily based out of Lake Hood and Spenard Lake. Military aircraft regularly utilize the airfield at Elmendorf AFB. Smaller aircraft also use public runways at Birchwood and Goose Bay in Knik Arm, Merrill Field, Girdwood, the Kenai Municipal Airport, Ninilchik, Homer, and Seldovia.

Water Quality

Sewage

Ten communities discharge treated municipal wastewater into Cook Inlet or its rivers (Fig. 12), with many cases of fecal-coliform counts exceeding safe levels documented in recent years (Table 4). Sewage receives primary treatment at Point Woronzof (in Region 1), the largest wastewater management facility serving Anchorage, and at smaller facilities serving English Bay, Port Graham, Seldovia, and Tyonek (all in Region 2). Point Woronzof can treat 44 million gallons/day (mgd) versus the 10,000 gallons/day to 1.6 mgd treated at the other facilities listed above (MMS[20]). In 1993, effluent discharged from Point Woronzof averaged 30 mgd with discharges of biochemical oxygen demand (BOD) averaging 25,800 lb/day, total suspended solids (TSS) averaging 12,300 lb/day, and oil and grease averaging 5,360 lb/day (which may contain petroleum hydrocarbons) (MMS[20]). Sewage from Homer, Kenai, and Palmer receives secondary treatment, while Girdwood and Eagle River wastewater facilities (both in Region 1) are modern, tertiary treatment plants (AWWU[21]). Specifically, Eagle River was expanded in 1991 and has a capacity of 2.5 mgd. Girdwood was upgraded in 1997 to handle 0.60 mgd. Septic tanks or other individual systems are used in the other communities that border Cook Inlet.

Military Bases

According to the USACE, Alaska District, Formerly Used Defense Site (FUDS[22]) Geographic Information System database, most of the military base sites around Cook Inlet (Fig. 12) never had, or have been cleared of, hazardous/toxic waste, ordinance, and unsafe debris. However, some of these sites were never visited by USACE, and state-of-the-site summaries are based upon contractor and private property owner's reports. The Eagle River Flats area near Fort Richardson was nominated in 1996 by the EPA superfund cleanup staff for listing under Section 303d of the Clean Water Act due to the presence of white phosphorous (from artillery shell residue) and its potential lethal effect on waterfowl using this area (ADEC[23]; EPA[24]). Several remediation projects have helped to reduce waterfowl mortality from several thousand to a few hundred per migratory season.

Contaminants

Mineral discharges of zinc, barium, cadmium, and mercury are monitored at known point sources that include oil production facilities, the Point Woronzof Wastewater Treatment Plant, military bases, fish processors, and municipalities of Cook Inlet. Barium is the major component of drilling mud (63% of drilling muds are comprised of the mineral barite (barium sulphite)), and both mercury and cadmium are found in barite (MMS[20]). Mercury has also been reported in the municipal wastewater effluent of the Point Woronzof plant (MMS[20]).

In 1991, the National Toxics Campaign Fund analyzed sediment samples, collected on the west shore of Cook Inlet near the mouth of the Drift River and in Trading Bay, which contained "higher than average" concentrations of barium but no detectable levels of polycylic aromatic hydrocarbons (PAH's), beryllium, or arsenic (DNR[7]). A 1993 MMS study compared heavy metal con-

[16] Komarnitsky, S. J. 2001. Valley port in trouble. Anchorage Daily News, 7 Feb.:A-1:A-8.

[17] McConnell, G. R. 2000. Beluga report: upper Cook Inlet navigation project. Unpubl. rep., 2 p., to Alaska Reg., Natl. Mar. Fish. Serv., 222 W. 7th Ave. #43, Anchorage, AK 99513

[18] Data obtained from the Municipality of Anchorage (MOA) website accessed 29 June 2000 [http://www.ci.anchorage.ak.us/services/departments/merrill/].

[19] Goldsmith, S. 1998. Anchorage International Airport 1998: economic significance. Report prep. for Anchorage International Airport [available at Inst. Social Econ. Res., Univ. AK, 3211 Providence Dr., Anchorage, AK 99508], 37 p.

[20] MMS. 1996. Cook Inlet planning area oil and gas lease sale 149: final environmental impact statement, vol. 1. U.S. Dep. Inter., OCS EIS/EA MMS 95-0066, v. p.

[21] Data obtained from the Anchorage Water & Wastewater Utility (AWWU) website, 10 February 1999 [http://www.awwu.ci.anchorage.ak.us/website/default.htm].

[22] Data obtained from the U.S. Army Corps of Engineers website, 11 February 1999 [http://knik.poa.usace.army.mil/].

[23] Data obtained from the Alaska Dep. Environ. Conserv., Air and Water Quality Div. (ADEC) website, 12 February 1999 [http://www.state.ak.us/dec/dawq/wqm/wqp/303d/303dl.htm].

[24] Data obtained from the Environ. Protect. Agency (EPA) website, 2 November 1999 [http://www.epa.gov/superfund/sites/npl/ak.htm].

Table 4.—Summary of sewage outfall fecal coliform exceedances in Cook Inlet. Partial listing summarized from: Alaska Department of Environmental Conservation, Air and Water Quality Division webpage [http://www.state.ak.us/dec/dawq/wqm/wqp/303d/303dl.htm].

Location	Outfall	Description
Cheney Lake, Anchorage	Fecal Coliform Urban Runoff Storm Drainage	On Section 303(d) list for fecal coliform since 1996. MOA 1991–94 data indicates fecal coliform criterion is being exceeded in almost every monitoring month.
Furrow Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1996. MOA data indicate levels of fecal coliform exceed the criteria for drinking water, primary contact recreation, and at times secondary contact recreation. Source of fecal coliform presumed to be human-caused from urban runoff sources.
Little Rabbit Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. Source of fecal coliform exceedances (human-caused or caused by non-human sources such as wildlife) has been an issue.
Little Survival Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. Source of fecal coliform exceedances (human-caused or caused by non-human sources such as wildlife) has been an issue.
Ship Creek—Glenn Hwy. Bridge, down to mouth, Anchorage	Fecal Coliform Petroleum Products Urban Runoff	On the Section 303(d) list for fecal coliform, biological community alteration, and petroleum hydrocarbons since 1994. MOA fecal coliform monitoring data indicates water quality criteria for drinking water and contact recreation were exceeded at times between 1989–94. EPA established a superfund site adjacent to Ship Creek. Petroleum products floating on ground water threaten the waterbody. A report for ADEC indicates the macroinvertebrate community has been altered/degraded. A recovery plan was completed in June 1998.
Campbell Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. There are several parameters of concern, i.e. temperature, turbidity, zinc, and lead, but the Creek was water quality limited for fecal coliform only.
Campbell Lake, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. The Campbell Creek water quality assessment, completed in June 1994, included an assessment of Campbell Lake. Results were similar to those found for Campbell Creek.
Chester Creek, Anchorage	Fecal Coliform Urban Runoff Industrial	On the Section 303(d) list for fecal coliform since 1994. The waterbody is water quality limited for fecal coliform only, though several other areas of concern were identified.
Fish Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform and turbidity since 1994. The waterbody was water quality-limited only for fecal coliform.
Hood/Spenard Lake, Anchorage	Dissolved Oxygen Urban Runoff Industrial Fecal Coliform	On the Tier I 1996 Section 303(d) list and proposed for Tier III for fecal coliform only because a TMDL for fecal coliform was developed and finalized on September 30, 1997. The waterbody will remain on the Tier II list for dissolved oxygen. There are four other pollutants of concern, petroleum, nitrates, lead, and ammonia, however, the data indicated no persistent violations.
Little Campbell Creek, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. The lake is water quality-limited only for fecal coliform.
University Lake, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. The waterbody is water quality-limited for only fecal coliform.
Westchester Lagoon, Anchorage	Fecal Coliform Urban Runoff	On the Section 303(d) list for fecal coliform since 1994. Westchester Lagoon is water quality-limited only for fecal coliform, however, there are water quality concerns related to iron, turbidity, and petroleum products.
Jewel Lake, Anchorage	Fecal Coliform Urban Runoff Land Development	On the 1996 Section 303(d) Tier I list for fecal coliform. A TMDL was developed and finalized and the waterbody is proposed for Tier III listing.

centrations to results obtained during OCSEAP studies conducted in the late 1970's and found "no immediate evidence of heavy metal pollution in Cook Inlet" (ENRI[25]). However, concentrations of terrestrial-source mercury at sampling stations in upper Cook Inlet were higher than the EPA designated chronic level but well below the acute toxicity level (ENRI[25]). From 1993 to 1997, the Cook Inlet Regional Citizens Advisory Council (CIRCAC) initiated studies similar to the 1993 MMS study. Overall, PAH concentrations were considerably lower than the amount expected to cause adverse effects in animals (ADL[26]; KLI[27]). In their 1997 report on the state of the inlet, CIK criticized the results of these studies as being inconclusive and emphasized the need for longer-term testing.

In 1997, MMS began a project to compare the chemical "fingerprints" of pollutants from sediment samples to their possible sources (ADL[28]). Sources included Cook Inlet crude oil, natural oil seeps, Municipality of Anchorage sewage outfall, and water from Homer Harbor. Preliminary results indicate no contamination in surface sediments or specimen tissues from oil and gas production; although, elevated levels of arsenic, copper, and mercury at some sites were due to local anthropogenic inputs and need further evaluation (ADL[28]). Anthropogenic inputs, however, accounted for only a small fraction of metals found in Cook Inlet. Compared to natural loadings from rivers and streams, these anthropogenic inputs contributed less than 1% of total metal transport in Cook Inlet and beyond, the only exception being barium which was 5.5% (ADL[28]).

[25] ENRI. 1995. Current water quality in Cook Inlet, Alaska, study. Environ. Nat. Resour. Inst., Univ. Alaska, Anchorage, OCS Study MMS 95-0009, 124 p.

[26] ADL. 1995. Cook Inlet pilot monitoring study: Phase II final report. Arthur D. Little, Inc., Cambridge, Mass., Ref. 46849, v.p.

[27] KLI. 1996. Cook Inlet environmental monitoring program: final report. Kinnetic Lab., Inc., Anchorage, Alaska, 59 p.

[28] ADL. 1998. Sediment quality in depositional areas of Shelikof Strait and outermost Cook Inlet: final literature synthesis. Arthur D. Little, Inc., Cambridge, Mass., OCS Study MMS 97-0015, 69 p.

Specimen tissues were also analyzed by the EPA in 1997 to determine if subsistence food resources were being contaminated by dioxins/furans, PAH's, pesticides, PCB's, and metals including inorganic arsenic, barium, cadmium, chromium, methyl mercury, and selenium (DNR[7]). More than 100 samples of subsistence fish, shellfish, and marine plants were tested. Similar to the CIRCAC Monitoring Program results, EPA preliminary results indicated that contaminant levels (regardless of their source) in sediments and tissues were at background levels or were undetectable, and did not pose a threat to Cook Inlet biota. However, PCB's and methyl mercury in sea bass (Serranidae), cadmium in snails (Prosobranchia), chitons (Polyplacophora), and octopus, *Octopus dolfleini*, and the pesticide dieldrin in chinook salmon could pose a health risk to humans depending on the quantity consumed and type of preparation. Organocholorines, such as PCB's and DDT, are dispersed worldwide as a result of agricultural and industrial activities, and there is concern that these synthetic chemicals impair health and reduce reproductive fitness in marine mammals (reviewed in Colborn and Smolen, 1996).

Potential Effects on Belugas

Belugas in Cook Inlet are subjected to various anthropogenic activities, from fishing operations, oil and gas exploration and development, intense vessel and air traffic, sewage, and contaminants, as well as the annual hunt conducted by Alaska Natives. It is possible that commercial and subsistence fishing in the upper inlet could have an impact on belugas, either from competition for fish or displacement from foraging habitat. Reports of belugas entangled in fishing gear are sporadic and few. From 1981 to 1984, at least 3–6 whales were taken incidental to commercial salmon fishing (Burns and Seaman[29]). Since 1988, there have been only three reported entanglements: 1) one beluga caught at Fire Island on 25 July 1989; 2) one beluga caught in a set gillnet near the Susitna River on 25 July 1990; and 3) one beluga caught in a fishing net in the Kenai area on 9 August 1996 (NMFS unpubl. data). Of note, there were no reports of entanglements in 1999, the first year that NMFS fishery observers were available to monitor fishing activities in the Category II Cook Inlet salmon gillnet fishery (NMFS unpubl. data). There were four observers in the upper inlet (Fire Island, Point Possession, Tyonek, and Susitna areas) and three in the lower inlet (Kenai, Nikiski, and McArthur areas). Currently there are no data to indicate that beluga mortality due to entanglement is significant.

Beluga hearing and responses to noise generated from oil and gas activities, geophysical surveys, dredging, construction, and the operation of vessels and aircraft are reviewed in Richardson et al. (1995); with their responses to noise from an icebreaker in the Bering Sea detailed in Erbe and Farmer (1998; 2000). Underwater noise from most of these activities are at relatively low frequencies (<1 kHz) where beluga hearing is poor; belugas hear best at frequencies between 10–15 kHz (Richardson et al., 1995). In the late 1970's and early 1980's, there were numerous reports of belugas seen near oil and gas structures (Hazard, 1988). McCarty (1981) reported groups, including females with calves, passing within 10 m of active platforms. Small groups of belugas (4–8 animals) were "commonly seen" near oil and gas platforms in Cook Inlet during winter but not in summer (Dahlheim[30]). There have been no confirmed reports of belugas near oil and gas structures in recent years.

Low frequency (i.e. long wavelength) sound travels poorly in shallow water, so transmission of these sounds in upper Cook Inlet is expected to be confined to relatively short ranges. This may partially explain the lack of response of 15 belugas to seismic exploration signals in Cook Inlet in June 1995 (Morris[31]). During that observation, the whales were in shallow *ca.* 2–7 m (6–20 ft) water, and the ship was in relatively deep *ca.* 20–27 m (60–80 ft) water about 37 km (20 n.mi.) from the whale group. In 1999, belugas were observed near the docks at the Port of Anchorage and in Knik Arm between Anchorage and Point MacKenzie during transits from the dredging operation off Fire Island, but none were reported close to the dredge site (McConnell[17]). According to the USACE[5], marine birds and mammals are rarely found in the immediate vicinity of marine dredging excavation or disposal sites in Cook Inlet, and these animals can easily avoid dredging operations.

Observed responses of belugas to vessels ranges from complete tolerance to extreme sensitivity, apparently depending on whale activities, habitat, boat type, and previous experience (Richardson et al., 1995). It appears that belugas can habituate to vessels that follow consistent routes (Burns and Seaman[29]). In addition, hundreds of commercial salmon fishing vessels in Bristol Bay do not deter belugas from feeding in the area (Frost et al.[32]). Even when purposefully harassed by powerboats, belugas continue to return to traditional estuarine areas in Cook Inlet (Lerczak et al., 2000).

It is uncertain if noise or visual cues from aircraft operating in the Anchorage area affect belugas. Richardson et al. (1995) found that in the Beaufort Sea, belugas dive or swim away when low-flying (<500 m) aircraft (either fixed-wing or helicopters) pass directly overhead. Lone animals and small groups responded more often than feeding whales. However, in eastern Hudson Bay, Canada, Caron and Smith (1990) observed no changes in swim directions of belugas when aircraft passed >300m overhead, which is consistent with observations from the survey aircraft flown at roughly 244 m in Cook Inlet (Rugh

[29] Burns, J. J., and G. A. Seaman. 1986. Investigations of belukha whales in the coastal waters of western and northern Alaska: II. Biology and ecology. U.S. Dep. Commer., NOAA, Natl. Ocean Serv., Anchorage, Alaska, Final Rep., Res. Unit 612, 129 p.

[30] Dahlheim, R. F., Jr. 16126 Dubuque Road, Snohomish, WA 98290. Personal commun.

[31] Morris, R., NMFS Alaska Reg. Off., Anchorage, AK 99513. Personal commun.

[32] Frost, K. J., L. F. Lowry, and R. R. Nelson. 1984. Belukha whale studies in Bristol Bay, Alaska. *In* B. R. Melteff and D. H. Rosenberg (Editors), Proc. workshop on biological interactions among marine mammals and commercial fisheries in the southeastern Bering Sea, p. 187–200. Univ. Alaska Sea Grant Rep. 84-1.

Table 5.–Categories defined by the National Marine Fisheries Service with specific recommendations regarding the use of proposed oil and gas development tracts in Cook Inlet. Source: Payne, text footnote 33.

Category one[1]		Category two[2]	
Location	Tract number	Location	Tract number
Chuitna River	494, 497, 498	Kustatan River	211, 257
Beluga River	485, 486, 493, 544, 547, 548, 549, 550, 551, 552, 559	Middle River	373, 376, 377
Ivan River	541	Drift River	177
Susitna River	536, 537, 538, 539, 540, 542, 543, 593, 594, 598	Big River	175, 218
Little Susitna River	529, 532, 533, 534, 535, 585, 586, 590	McArthur River	301, 320, 384
Knik Arm	575, 576, 577, 579, 581, 582, 616, 617, 618, 620, 621, 622, 623, 627, 655, 656, 657, 658, 662	Kenai River	126, 127, 129, 130, 131, 132, 161, 162
Anchorage	522, 524, 525, 526, 527, 528, 530, 531		
Chickaloon River	322, 323, 324, 325, 326, 327, 329, 331		
Turnagain Arm	320, 321, 328, 330, 333, 334, 391, 392, 393, 394, 395, 396, 397, 398, 399, 400, 401, 402, 403, 404, 405, 406, 407, 408, 409, 462, 464, 465, 466, 467, 468, 469, 470, 471, 472, 473, 474, 475		

[1] Oil and gas exploration and development (permanent or temporary) should not occur on these tracts, excluding upland areas (above Mean Higher High Water).

[2] Leasing of these tracts should be conditioned such that no permanent surface entry or structures occur, excluding upland areas, and temporary activities and structures occur only between November 1 and April 1 of each year.

et al., 2000). Belugas are probably less sensitive to aircraft noise than to vessel noise, but their response may be highly variable as a function of previous experience, activity, and characteristics of the noise.

In other regions, belugas have demonstrated a strong attachment to certain estuaries, a behavior referred to as site tenacity or fidelity (Finley, 1982; Finley et al., 1982; Caron and Smith, 1990). These belugas continue to return to estuaries after a disturbance and, surprisingly, adults accompanied by calves were usually the first to return. Similar site fidelity appears to be demonstrated by belugas in Cook Inlet (Lerczak et al., 2000). Although Cook Inlet belugas continue to occupy the upper inlet despite oil and gas development, vessel and aircraft traffic, and dredging operations, the cumulative impacts of these activities are not known.

Water quality is also of particular concern to Alaska Native hunters in Cook Inlet (Huntington, 2000). Specifically, hunters maintain that, in addition to garbage along the beaches, the water itself smells bad, there is more foam along the beaches, and that effluent from oil rigs and other sources may be affecting the health of fish and therefore belugas in Cook Inlet. Belugas, harbor seals, sea otters, and their prey depend on inshore waters, areas where oil tends to accumulate (Geraci and St. Aubin, 1990). Belugas confined to small leads during heavy ice years could be especially at risk if the open water was contaminated with unweathered oil (Hansen, 1992). Concerned that oil and gas exploration and development might affect Cook Inlet belugas, NMFS recommended deleting specific tracts from the DNR's 1999 lease sale (Payne[33]). The tracts were divided among three categories. Category One tracts represented areas heavily used by belugas during summer (Table 5). It was recommended that oil and gas development (permanent or temporary) not occur in these areas, excluding those areas above Mean Higher High Water. Category Two included tracts used by belugas during summer periods (Table 5). These tracts should be leased on condition that "no permanent surface entry or structures occur, other than in upland areas, and that all temporary activities and structures (e.g. exploration drilling) occur only between 1 November and 1 April of each year." No specific recommendations were made for the remaining sale tracts which were placed under Category Three.

Additional sources of potential contamination include the EPA superfund site at Eagle River Flats. This area is of particular concern as belugas are known to congregate at the mouth of the Eagle River and at times to enter the river (Rugh et al., 2000; NMFS unpubl. data). Although Cook Inlet belugas inhabit a region of comparatively high anthropogenic development, they do not carry higher loads of PCB's and chlorinated pesticides and apparently have lower concentrations of some compounds (e.g. chlordane, HCB, and dieldrin and heavy metals) than whales from two other Alaska beluga stocks (Becker et al., 2000; Krahn et al., 1999). The principle source of PCB's, toxaphene, DDT, chlordane, HCB, and dieldrin in Arctic populations of belugas is hypothesized to be atmospheric transport from lower latitudes (Pacyna, 1995).

[33] Payne, P. M., NMFS, Office of Protected Resources, in letters 19 and 30 Nov. 1999 to Patty Bielawski, Dep. Nat. Resour.

Conclusions

Beluga habitat associations are summarized by region (Fig. 1) in Table 6. In Region 1, the largest beluga concentrations in summer are associated with very shallow, low-salinity water at the outflow of major rivers in the upper inlet. Prey availability is probably high and varies with annual fish runs. Occurrence of killer whales (predators) is low, only a small number of entanglements in fishing nets have been reported, and potential disturbance from petroleum activities is not considered a key determinant to distribution at this point. Although stranding occurs fairly often, mortality associated with it seems to be low. Vessel traffic is high (particularly near Anchorage) and due to sewage outfalls water quality comparatively poor in Region 1. Region 2 is similar to Region 1 with the exceptions of increased petroleum activities along the western shore and reduced shipping activity. In winter, belugas were seen primarily in Region 3. However, it is also possible that belugas in heavy-ice cover nearshore may have been missed by aerial observers. Water depth in Region 3 varies from shallow to the deepest channels in Cook Inlet,

the water column is comparatively well mixed, and sea-ice varies from open water to >90% surface cover. Fishing activity is largely absent in winter, although potential disturbance from petroleum transportation activities continue year-round. Water quality in the central inlet is described as "good" due to mixing effects of tidal flushing.

This descriptive account of beluga habitat associations in Cook Inlet could be greatly improved by the incorporation of quantifiable measures of habitat variability. While it is well established that belugas follow fish runs, our capability to assess the importance of prey availability to habitat selection would be greatly improved by quantification of fish runs coordinated with whale surveys. This would help determine factors critical to the belugas' known selection of only a few rivers. Similarly, measures of anthropogenic factors (i.e. fishing, underwater noise, and water quality), both within and outside of beluga concentration areas, would allow a better assessment of beluga habitat quality and selection criteria.

Table 6.—Physical, ecosystem, and anthropogenic habitat factors that may affect beluga distribution in three regions of Cook Inlet, Alaska, based on density of whale sightings.

Item	Region 1	Region 2	Region 3
Beluga distribution			
Summer	High	Moderate	Low
Winter	Occasional	Occasional	Moderate
Physical factors			
Bathymetry	Shoals and shallow	Shallow	Deep channels
Salinity (summer only)	Fresh	Fresh	Fresh, saline
Sea ice (winter only)	Ice covered	Brash ice	Brash and ice free
Tides and currents	Extreme & variable	Extreme & variable	Moderate & channeled
Ecosystem factors			
Prey variability	Dense fish runs?	Fish runs?	Dispersed fish runs?
Predators	Low	Low	Low?
Strandings	High	High	Low
Natural catastrophe	Unknown	Unknown	Unknown
Anthropogenic factors			
Fishing and bycatch	Low	Low	Low
Petroleum	Low	Moderate (west)	High (west)
Transportation	High (Anchorage)	Low	High
Water quality	Poor	Poor	Moderate

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Concentrations of Polychlorinated Biphenyls (PCB's), Chlorinated Pesticides, and Heavy Metals and Other Elements in Tissues of Belugas, *Delphinapterus leucas*, from Cook Inlet, Alaska

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Introduction

The beluga, *Delphinapterus leucas*, is circumpolar Arctic in distribution and occurs in individual stocks throughout its range. Many of these stocks are distinct, genetically separate populations (e.g. St. Lawrence River estuary population in eastern Canada; Cook Inlet population in northwestern Gulf of Alaska), while for many other groups the degree of population separation is questionable. Based on the previous suggestions by Frost and Lowry (1990) and recent genetic evidence by O'Corry-Crowe et al. (1997), there appear to be two populations in Alaska (Cook Inlet and Bering Sea) containing five beluga whale stocks.

The Cook Inlet stock represents a geographically isolated, subarctic population of this species. The remaining four Alaska stocks, comprising the Bering Sea population, are the Bristol Bay, Norton Sound, eastern Chukchi Sea, and eastern Beaufort Sea stocks. The majority of the Bering Sea population appear to spend the winter in ice-free areas of the Bering Sea, while some may overwinter in polynyas of the Bering Strait and Chukchi Sea, and in the Gulf of Anadyr and Bristol Bay (Hazard, 1988; Frost and Lowry, 1990). Although Cook Inlet belugas may be found there during all seasons, they occasionally appear in the Gulf of Alaska as far east as Yakutat and as far west as the Shelikof Strait (Calkins and Pitcher, 1977; Hubbard et al., 1999). The move-

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ABSTRACT—Tissues from Cook Inlet beluga whales, Delphinapterus leucas, *that were collected as part of the Alaska Marine Mammal Tissue Archival Project were analyzed for polychlorinated biphenyls (PCB's), chlorinated pesticides, and heavy metals and other elements. Concentrations of total PCB's (∑PCB's), total DDT (∑DDT), chlordane compounds, hexachlorobenzene (HCB), dieldrin, mirex, toxaphene, and hexachlorocyclohexane (HCH) measured in Cook Inlet beluga blubber were compared with those reported for belugas from two Arctic Alaska locations (Point Hope and Point Lay), Greenland, Arctic Canada, and the highly contaminated stock from the St. Lawrence estuary in eastern Canada. The Arctic and Cook Inlet belugas had much lower concentrations (∑PCB's and ∑DDT were an order of magnitude lower) than those found in animals from the St. Lawrence estuary. The Cook Inlet belugas had the lowest concentrations of all (∑PCB's averaged 1.49 ± 0.70 and 0.79 ± 0.56 mg/kg wet mass, and ∑DDT averaged 1.35 ± 0.73 and 0.59 ± 0.45 mg/kg in males and females, respectively). Concentrations in the blubber of the Cook Inlet males were significantly lower than those found in the males of the Arctic Alaska belugas (∑PCB's and ∑DDT were about half). The lower levels in the Cook Inlet animals might be due to differences in contaminant sources, food web differences, or different age distributions among the animals sampled. Cook Inlet males had higher mean and median concentrations than did females, a result attributable to the transfer of these compounds from mother to calf during pregnancy and during lactation. Liver concentrations of cadmium and mercury were lower in the Cook Inlet belugas (most cadmium values were <1 mg/kg and mercury values were 0.704–11.42 mg/kg wet mass), but copper levels were significantly higher in the Cook Inlet animals (3.97–123.8 mg/kg wet mass) than in Arctic Alaska animals and similar to those reported for belugas from Hudson Bay. Although total mercury levels were the lowest in the Cook Inlet population, methylmercury concentrations were similar among all three groups of the Alaska animals examined (0.34–2.11 mg/kg wet mass). As has been reported for the Point Hope and Point Lay belugas, hepatic concentrations of silver were relatively high in the Cook Inlet animals and positively correlated with mercury and selenium concentrations in the liver.*

ment of these animals out of Cook Inlet and into the relatively ice-free Gulf of Alaska may occur during conditions of heavy ice in Cook Inlet (Calkins, 1983; Hansen and Hubbard, 1999).

The beluga whale is an important subsistence food resource across the North American Arctic. In Alaska, about 30 coastal villages of the Arctic Ocean and Bering Sea and communities located in Cook Inlet regularly take this species for food. The beluga is hunted primarily for its meat and maktaaq (i.e. skin plus blubber). These products are both consumed locally and are frequently distributed to villages that do not have access to this resource. As a result of the recent decline in the numbers of Cook Inlet belugas and in response to petitions from the State of Alaska and several organizations, NOAA's National Marine Fisheries Service (NMFS) has proposed that this population of belugas be listed as depleted under the Marine Mammal Protection Act (Fed. Regist., 19 Oct. 1999).

Belugas have the potential to accumulate relatively high concentrations of persistent contaminants in their tissues. This species feeds near the top of the marine food web and is therefore exposed to chemicals that accumulate and are biomagnified in the food chain (e.g. mercury, polychlorinated biphenyls (PCB's), etc.). The diets of these toothed cetaceans (odontocetes) vary depending on the summering areas of the individual stocks and the annual and seasonal variability in the abundance of suitable prey. Prey species include various fishes, crangonid shrimp, squid, and octopus (Calkins, 1983; Seaman et al., 1986).

The beluga whale is relatively long-lived (>35 yr) and maintains a thick layer of lipid-rich blubber, thus providing a storage depot for the accumulation of lipophilic contaminants (e.g. PCB's and chlorinated pesticides). For all animals, persistent organic contaminants are lipophilic (tending to associate with lipids) and accumulate in body fat. Mammals have various physiological mechanisms for metabolizing and excreting these compounds, the efficacy of which varies among species and depending on the chemical characteristics of the individual compounds. Although mechanisms for ridding the body of these compounds are available, the processes are usually slow, and the tendency is for the materials to accumulate in body fat over time. The beluga whale is common in nearshore waters and can be commonly found several kilometers up major river systems. Due to this behavior, this species has the potential to be exposed to coastal anthropogenic contaminants.

An important source of exposure to consider for all higher latitude biota, including belugas, is the apparently pervasive release of persistent contaminants in lower latitudes and their transport to remote areas. Many studies have documented global contamination by persistent organic contaminants and the role that atmospheric transport plays in the movement of such compounds from lower to higher latitudes (Barrie et al., 1992; Wania and Mackay, 1993; Iwata et al., 1994; Tanabe et al., 1994). Ocean currents probably also play a role, particularly for transport in ice-covered seas and for those compounds that are relatively hydrophilic (e.g. HCH and toxaphene). It is generally accepted that, except for localized "hot spots" of anthropogenic contamination, the anthropogenic contaminant concentrations reported for tissues of North American Arctic marine mammals probably originate from lower latitudes.

Since 1992, blubber, liver, kidney, and muscle specimens have been collected as part of the Alaska Marine Mammal Tissue Archival Project (AMMTAP) from beluga whales taken by Alaska Native subsistence hunters in Cook Inlet and archived under cryogenic conditions at the National Biomonitoring Specimen Bank at the National Institute of Standards and Technology, Gaithersburg, Md. The AMMTAP, which began in 1987 as part of the Outer Continental Shelf Environmental Assessment Program (OCSEAP), is described in Becker et al. (1988). In addition to Cook Inlet beluga whales, AMMTAP, in collaboration with the North Slope Borough Department of Wildlife Management, has obtained tissue samples from belugas taken in subsistence hunts from Point Hope (eastern Beaufort Sea stock) and Point Lay, Alaska (eastern Chukchi Sea stock). The eastern Beaufort Sea stock is thought to include the animals that migrate with bowhead whales, *Balaena mysticetus*, during the latter's spring migration and that spend the summer at the mouth of the Mackenzie River and Amundsen Gulf in the eastern Beaufort Sea (O'Corry-Crowe et al., 1997). The eastern Chukchi Sea stock includes animals of Kotzebue Sound as well as those that occur at Kasegaluk Lagoon (Point Lay) during the summer.

Aliquots of the Cook Inlet specimens, collected by the AMMTAP and archived in the NBSB, and additional samples collected from the same animals were analyzed for persistent organic contaminants (i.e. PCB's, and chlorinated pesticides) and inorganic constituents (elements), including heavy metals, and methylmercury. The results of the analyses for persistent organic contaminants for the Cook Inlet animals as well as the eastern Beaufort Sea and eastern Chukchi Sea belugas have been recently published elsewhere as part of an overall report on the concentration of these compounds in Alaskan beluga whales (Krahn et al., 1999). In addition, data have been published on belugas from Canada and Greenland that can be used for comparisons with the Cook Inlet animals (Deitz et al., 1990; Hansen et al., 1990; Muir et al., 1990b; Wagemann et al., 1990; Stern et al., 1994; Wagemann et al., 1996; Wade et al., 1997; Muir et al., 1999). This paper compares the tissue concentrations of PCB's, chlorinated pesticides, and elements (including heavy metals) in the Cook Inlet belugas with concentrations reported for the eastern Chukchi Sea and eastern Beaufort Sea animals, and Canadian and Greenland belugas.

Methods

Specimen Collections

Cook Inlet beluga blubber, liver, and kidney were selected for analyses from specimens stored under cryogenic conditions (–150°C) in the National Biomonitoring Specimen Bank at the National Institute of Standards and Technology (NIST) (Wise and Koster, 1995). These specimens were collected from

1992 to 1996 by the NMFS Western Alaska Field Office in collaboration with local Alaska Native hunters and with the support of the Alaska Beluga Whale Committee (Table 1). Collection procedures followed those standard AMMTAP protocols designed to preserve sample integrity and minimize sample contamination from handling (Becker et al., 1991). Blubber specimens consisted of whole thickness sections of blubber from the skin to the muscle, while kidney specimens consisted of whole kidney tissue (cortex and medulla). The gender of each animal and standard body measurements were recorded. Standard body measurements included: standard length (rostrum to fluke notch), axillary girth, fluke width, and blubber thickness. Teeth were collected, and the age of each animal was determined based on number of growth layer groups counted in a thin longitudinal section taken from the middle of the mandibular tooth (Burns and Seaman, 1986). Ages were determined by Robert Suydam, North Slope Borough Department of Wildlife Management, Barrow, Alaska, and Barbara Mahoney, NMFS, Anchorage, Alaska.

Table 1.—Cook Inlet belugas sampled for persistent organic contaminant and element analyses.

Animal ID no.	Gender	Age (yr)	Length (cm)	Tissues	Date sampled	Comment
692-BLKA-015	M	8.5	374	Blubber, liver	6 Oct. 1992	
692-BLKA-016	M	Adult	472	Blubber	23 July 1994	
692-BLKA-017	F	Unknown	305	Blubber	22 July 1994	
692-BLKA-018	M	Unknown	305	Blubber	23 July 1994	
692-BLKA-020	F	2	240	Blubber, liver	20 May 1995	
692-BLKA-021	M	10.5	409	Blubber, liver	3 June 1995	
692-BLKA-022	F	10	360	Blubber, liver	9 May 1995	
692-BLKA-023	F	12.5	353	Blubber, liver	1 June 1995	
692-BLKA-024	F	15	368	Blubber, liver	5 June 1995	With fetus
692-BLKA-025	F	Fetus	142.5	Blubber, liver	5 June 1995	Near term
692-BLKA-026	M	Adult	422	Blubber, liver	19 June 1995	
692-BLKA-027	M	9	377	Blubber, liver	27 June 1995	
692-BLKA-028	M	9	391	Blubber, liver	28 June 1995	
692-BLKA-029	M	Adult	413	Liver	11 Aug. 1995	
692-BLKA-031	F	Adult	367	Blubber	18 June 1995	Lactating
692-BLKA-032	F	Adult	256	Blubber	15 July 1996	
692-BLKA-033	F	Adult	359	Blubber	30 July 1996	Lactating
692-BLKA-034	F	Adult	377	Blubber	29 Aug 1997	
692-BLKA-035	M	Adult	415	Blubber	7 Oct. 1996	
692-BLKA-036	M	Adult	429	Blubber	7 Oct. 1996	
692-BLKA-037	M	Adult	367	Blubber	7 Oct. 1996	

Sample Preparation

Each tissue specimen to be analyzed (approximately 150 g) was homogenized using a cryogenic procedure designed to reduce the likelihood of changes in sample composition due to thawing and refreezing (Zeisler et al., 1983). Samples of this tissue homogenate, a frozen (nonfreeze-dried) powder, were aliquoted into Teflon[1] jars (10 mL) for storage (at – 80°C) until analyses were performed.

PCB and Chlorinated Pesticide Analyses

Analyses for PCB congeners and chlorinated pesticides were performed at the NIST Gaithersburg, Md., Laboratory, NMFS Northwest Fisheries Science Center (NWFSC), Seattle, Wash., and the Department of Fisheries and Oceans (DFO), Winnipeg, Man., Can. NIST methodology has been described in detail by Schantz et al. (1996). Samples (2–3 g) were mixed with sodium sulfate (approximately 100 g), internal standards were added, and the mixture Soxhlet extracted (18 h) using methylene chloride. The majority of lipids and biogenic material were removed by size exclusion chromatography (SEC) and then polychlorinated biphenyl (PCB) and pesticides fractions were isolated by normal-phase liquid chromatography (LC) on a semi-preparative-scale aminopropylsilane column. The fractions were analyzed by gas chromatography with electron capture detection (GC-ECD). NIST Standard Reference Materials (SRM's) 1588 (Organics in Cod Liver Oil) and 1945 (Organics in Whale Blubber) were analyzed with each set of samples for quality control.

Analytical procedures used by the NWFSC have been described by Krahn et al. (1988) and Sloan et al. (1993). Samples (1–3 g) were extracted following addition of internal standards, by maceration with sodium sulfate and methylene chloride. The methylene chloride extract was then filtered through a column of silica gel and alumina and concentrated for additional cleanup. High-performance liquid chromatography (HPLC) with a size-exclusion column was used to separate lipids and other biogenic material from a fraction containing the PCB's and chlorinated pesticides. This fraction was analyzed by GC-ECD and identification of individual compounds was performed in selected samples by GC-mass spectrometry. NIST SRM 1945 was analyzed with each set of samples.

DFO analytical procedures have been described by Muir et al. (1988 a,b), Muir et al. (1990a), and Stern et al. (1994). Samples (2–5 g) were mixed with anhydrous sodium sulfate and extracted by ball-milling (30 min) with hexane following addition of internal standards. The extract was allowed to stand for 4 h and then centrifuged (1,000 rpm). Lipids were removed using size exclusion chromatography (SEC), and three fractions were obtained using Florisil. The fractions (PCB congeners/4,4'-DDE/mirex, toxaphene/chlordane/mirex, heptachlor epoxide, and dieldrin) were then analyzed by GC-ECD using the same type of column as employed by NIST. SRM's 1588 and 1945 were analyzed with every 20 blubber samples for quality control. Toxaphene was quantified with a modification of previously published procedures (Muir et al., 1988b; Stern et al., 1994). Response factors for individual toxaphene peaks were calculated from weight percent of each peak in the total ion chromatogram of a toxaphene standard as determined by electron impact mass spectrometry on a GC-mass selective detector. Total toxaphene (ΣToxaphene) was the sum of the concentrations of 19 peaks (Muir et al., 1990b).

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

The three laboratories that contributed data to this paper participate in an annual interlaboratory comparison exercise as part of the marine mammal quality assurance component of the NMFS Marine Mammal Health and Stranding Response Program. The results of these analyses were in good agreement (Schantz et al., 1996; Becker et al., 1999). Also, any differences among the laboratories for specific analytes were much less than the final differences between belugas from different locations using the databases from any of the three laboratories. Therefore, combining databases and using the means for samples for which there were results from more than one laboratory was justifiable.

Element Analysis

Instrumental neutron activation analysis (INAA) was used by NIST to analyze liver and kidney samples. INAA is a multielement analytical technique that provides data for a large number of trace elements using only a limited amount of sample. The INAA method is used routinely to measure 37 elements in the NBSB specimens: sodium (Na), magnesium (Mg), aluminum (Al), chlorine (Cl), potassium (K), calcium (Ca), scandium (Sc), vanadium (V), manganese (Mn), iron (Fe), cobalt (Co), copper (Cu), zinc (Zn), arsenic (As), selenium (Se), bromine (Br), rubidium (Rb), strontium (Sr), molybdenum (Mo), silver (Ag), cadmium (Cd), tin (Sn), antimony (Sb), iodine (I), cesium (Cs), barium (Ba), lanthanum (La), cerium (Ce), samarium (Sm), europium (Eu), terbium (Tb), hafnium (Hf), tantalum (Ta), gold (Au), mercury (Hg), thorium (Th), and uranium (U).

The INAA method, previously detailed by Mackey et al. (1995, 1996), consists of exposing samples and standards to a neutron field to produce radioactivity and measuring the energy and amount of resulting radiation. In preparation for INAA, subsamples of the frozen powder were lyphilized at a pressure of 1 Pa for 5 days during which the temperature was gradually increased from –20°C to 5°C. The dried powder was weighed into two 200 mg aliquots and each aliquot formed into a disk using a commercial stainless steel die and hydraulic press. The disks were packaged individually in acid-washed linear polyethylene (LPE) film. Since Hg analysis cannot be performed on these packaged disks due to permeation of volatile Hg into the film during irradiation, two 100 mg aliquots of the powder were placed in acid-washed quartz vials. The vials were flash frozen in liquid nitrogen prior to sealing to avoid any evaporative losses of elemental Hg or Hg compounds.

For each analysis, aliquots of powdered SRM's were packaged in the same way and were included in the analysis scheme for the purpose of quality control. Standards consisting of known amounts of each element were deposited onto filter papers, and formed into disks to insure consistent counting geometry between samples, controls, and standards. Analyses of SRM 1577a Bovine Liver and, beginning in 1991, a QA pilot whale liver tissue homogenate (Wise et al., 1993) were included with all multielement INAA measurements. Analyses of SRM 2710 Montana Soil and SRM 1571 Orchard Leaves were included with all Hg measurements. The irradiation and counting times for INAA were chosen to optimize the number of elements that can be determined and the detection limits for each. All irradiations were done at the NIST Reactor at a reactor power of 20 MW, which corresponds to a neutron fluence rate of approximately 2.0×10^{13} $cm^{-2}s^{-1}$.

In addition to INAA, total mercury analysis was performed at NIST using cold vapor atomic absorption spectrometry (CVAAS) following microwave digestion. For this procedure, 0.5 g of frozen homogenate was placed in a 100 mL Teflon PFA microwave container and the sample dissolved by microwave digestion using an acid mixture of 4 mL of HNO_3, 2 mL of $HClO_4$, and 0.5 mL of HF. After digestion and cooling, the sample was transferred to a 30 mL polypropylene bottle and diluted to a final volume of 25 mL with high-purity water containing 1% $K_2Cr_2O_7$. The weight and density of the final solutions were used in the calculation of the analyte concentration. The sample was then analyzed by cold vapor generation using the FIAS-200 flow injection system and Perkin-Elmer 5000 AAS. Standards were prepared from a 1,000 mg/mL stock standard. Two or three separate analysis runs (with a new set of calibration standards prepared for each run) were made for each sample preparation. Two or three separate sample preparations were made for each sample.

Methylmercury Analysis

Methylmercury analysis was performed at NIST using gas chromatography with atomic emission detection (GC-AED) as described by Donais et al. (1996). For this procedure, four methylmercury chloride calibration solutions and one ethyl mercury chloride internal standard solution were prepared gravimetrically in toluene. Subsamples of 0.2–0.5 g of frozen homogenates of the liver and kidney samples were extracted in 1 mL $CuSO_4$ solution (16 g of $CuSO_4$ to 100 mL of water), 4 mL acidic KBr solution (18 g of KBr and 5 mL concentrated H_2SO_4 diluted to 100 mL with chromatography grade water), and 2 mL toluene. Approximately 5 g of activated copper powder was added to each subsample prior to extraction. Following 1 h of agitation, each sample was centrifuged and the separated toluene layer was removed. The sample was extracted a second time with 2 mL of toluene (agitation for 10 min), the two toluene extractions combined, and the extracts for each sample/standard were spiked with a known mass of internal standard solution. The spiked extract was then concentrated to 0.5 mL and injected onto a preparative size exclusion chromatography column to remove lipids and biogenic material. One aliquot of each standard solution and one subsample of each tissue were extracted and analyzed by GC-AED in triplicate. NIST Pilot Whale Liver Control Material was analyzed with each set of samples for quality control.

Results and Discussion

PCB's and Chlorinated Pesticides

Results from analyses of blubber from 20 Cook Inlet beluga whales (10 males and 10 females) for PCB's and chlorinated pesticides are shown in Tables

Table 2.—Concentrations of ∑PCB, ∑DDT, ∑toxaphene, and ∑chlordane in blubber of Cook Inlet belugas compared with that reported for belugas from other North American locations. Values (mg/kg wet mass) are given as mean ±1 standard deviation.

Location (Date)	Gender	*n*	Age (yr)	∑PCB's	∑DDT	∑Toxaphene	∑Chlordane	Ref.[2]
West Greenland (1989–90)	M	71		5.38 ± 2.27	4.06 ± 2.50	3.69 ± 1.46	2.41 ± 1.08	1
Nuussuaq/ Disko Bugt	F	67		3.74 ± 2.31	2.60 ± 1.94	3.01 ± 1.62	1.79 ± 1.11	1
Cumberland Sound (1983)	M	6	7.3 ± 6.5	4.91 ± 0.25	6.83 ± 1.89	5.78 ± 5.39	2.38 ± 0.40	2
Pangnirtung	F	6	8.1 ± 7.3	1.15 ± 0.41	0.93 ± 0.55	1.77 ± 1.76	0.62 ± 0.15	2
St. Lawrence (1986–87)	M	4	17.5 ± 9.1	75.8 ± 15.3	101 ± 32.6	14.7 ± 2.46	7.43 ± 0.63	2
estuary	F	5	15.6 ± 10.4	37.3 ± 22.0	23.0 ± 17.3	6.34 ± 3.51	3.55 ± 1.99	2
E. Hudson Bay (1984–85)	M	6	15.6 ± 10.4	2.77 ± 0.51	2.27 ± 0.68	4.13 ± 0.82	1.86 ± 0.35	2
Nastapoka	F	6	17.0 ± 6.3	1.23 ± 0.84	0.98 ± 0.73	1.99 ± 1.10	0.87 ± 0.58	2
W. Hudson Bay (1986)	M	4	13.0 ± 4.8	3.12 ± 0.34	3.13 ± 0.20	5.10 ± 0.42	2.33 ± 0.26	2
Eskimo Point	F	4	10.3 ± 4.1	0.96 ± 1.00	0.85 ± 0.96	1.77 ± 1.41	0.85 ± 0.80	2
Jones Sound (1986)	M	8	4.4± 2.2	2.53 ± 0.57	1.96 ± 0.32	4.25 ± 1.02	1.87 ± 0.44	2
Grise Fjord	F	7	4.6 ± 2.9	2.46 ± 1.98	2.19 ± 1.69	3.74 ± 2.12	1.84 ± 1.13	2
Beaufort Sea (1983, 1987, 1989)	M	10	17.0[3]	3.33 ± 0.85	2.20 ± 0.83	3.83 ± 1.16	1.75 ± 0.41	2
Mackenzie R. & Point Hope	F	4	10.2 ± 7.0[4]	1.80 ± 0.77	0.95 ± 0.38	2.22 ± 1.05	0.99 ± 0.46	2, 3, 4
E. Chukchi Sea (1990,1996)	M	11	12.2 ± 4.5[5]	5.20 ± 0.90	3.63 ± 0.90	3.93 ± 1.16	2.42 ± 0.46	3, 4
Point Lay, AK	F	8	16.4 ± 7.5	1.50 ± 1.12	0.93 ± 0.85	2.62 ± 2.07	0.79 ± 0.61	3, 4
Cook Inlet, AK (1992–97)	M	10	9.2 ± 0.9[6]	1.49 ± 0.70	1.35 ± 0.73	2.40 ± 1.06	0.56 ± 0.25	3, 4
	F	10	9.9 ± 5.6[6]	0.79 ± 0.56	0.59 ± 0.45	2.02 ± 0.46	0.30 ± 0.22	3, 4

[1] ∑PCB's for the Beaufort Sea, eastern Chukchi Sea, and Cook Inlet animals are from Krahn et al. (1999). For the other beluga whale stocks, ∑PCB's are from Muir et al. (1990b). ∑Chlordane is the sum of the concentrations of heptachlor, heptachlor epoxide, *cis*-chlordane, *trans*-chlordane, *trans*-nonachlor, *cis*-nonachlor, oxychlordane, and nonachlor III. ∑DDT is the sum of the concentrations of 2,4′-DDT, 4,4′-DDT, 2,4′-DDD, 4,4′-DDD, 2,4′-DDE, and 4,4′-DDE.

[2] 1 = Stern et al. (1994); 2 = Muir et al. (1990b); 3 = Becker et al. (1995b); 4 = Krahn et al. (1999).

[3] $n = 2$.

[4] $n = 3$.

[5] $n = 10$.

[6] $n = 4$.

Table 3.—Concentrations of dieldrin, HCB, ∑HCH, and mirex in blubber of Cook Inlet belugas compared with that reported for belugas from other North American locations. Values (mg/kg wet mass) are given as mean ± 1 standard deviation.

Location (Date)	Gender	*n*	Age (yr)	Dieldrin	HCB	∑HCH[1]	Mirex	Ref.[2]
Cumberland Sound (1983)	M	6	7.3 ± 6.5	0.91 ± 0.26	0.96 ± 0.18	0.39 ± 0.11	0.01 ± 0.01	2
Pangnirtung	F	6	8.1 ± 7.3	0.20 ± 0.33	0.18 ± 0.04	0.24 ± 0.06	0.01 ± 0.00	2
St. Lawrence (1986–87)	M	4	17.5 ± 9.1	0.93 ± 0.12	1.34 ± 0.44	0.37 ± 0.11	1.00 ± 0.64	2
estuary	F	5	15.6 ± 10.4	0.56 ± 0.31	0.60 ± 0.43	0.24 ± 0.10	1.11 ± 0.99	2
E. Hudson Bay (1984–85)	M	6	15.6 ± 3.0	0.28 ± 0.09	0.30 ± 0.19	0.21 ± 0.06	0.02 ± 0.01	2
Nastapoka	F	6	17.0 ± 6.3	0.14 ± 0.10	0.14 ± 0.12	0.15 ± 0.04	0.01 ± 0.01	2
W. Hudson Bay (1986)	M	4	13.0 ± 4.8	0.36 ± 0.07	0.61 ± 0.05	0.24 ± 0.07	0.36 ± 0.07	2
Eskimo Point	F	4	10.3 ± 4.1	0.14 ± 0.12	0.19 ± 0.18	0.15 ± 0.04	0.14 ± 0.12	2
Jones Sound (1986)	M	8	4.4 ± 2.2	0.34 ± 0.11	0.50 ± 0.21	0.19 ± 0.09	0.01 ± 0.00	2
Grise Fjord	F	7	4.6 ± 2.9	0.33 ± 0.23	0.39 ± 0.21	0.16 ± 0.08	0.01 ± 0.01	2
Beaufort Sea (1983, 1987, 1989)	M	10	17.0[3]	0.23 ± 0.05	0.59 ± 0.13	0.23 ± 0.06	0.04 ± 0.01	2
Mackenzie R. & Point Hope	F	4	10.2 ± 7.0[4]	0.16 ± 0.08	0.42 ± 0.29	0.27 ± 0.12	0.02 ± 0.01	2, 3, 4
E. Chukchi Sea (1990,1996)	M	11	12.2 ± 4.5[5]	0.39 ± 0.09	0.81 ± 0.12	0.33 ± 0.76	0.06 ± 0.02	3, 4
Point Lay, AK	F	8	16.4 ± 7.5	0.12 ± 0.10	0.23 ± 0.28	0.25 ± 0.12	0.02 ± 0.01	3, 4
Cook Inlet, AK (1992–97)	M	10	9.2 ± 0.9[6]	0.09 ± 0.05	0.22 ± 0.09	0.21 ± 0.07	0.01 ± 0.01	3, 4
	F	10	9.9 ± 5.6[6]	0.06 ± 0.05	0.15 ± 0.13	0.17 ± 0.05	0.01 ± 0.00	3, 4

[1] The sum of α-, β-, and γ-HCH.

[2] 1 = Stern et al. (1994); 2 = Muir et al. (1990b); 3 = Becker et al. (1995b); 4 = Krahn et al. (1999).

[3] $n = 2$.

[4] $n = 3$.

[5] $n = 10$.

[6] $n = 4$.

2 and 3 together with data for animals from Point Lay (eastern Chukchi Sea), Point Hope and Mackenzie River (eastern Beaufort Sea), five additional locations in Canada, and one location in Greenland. The sampling locations are shown in Figure 1. Data for the Alaska animals were previously reported by Becker et al. (1995b), Becker et al. (1997), and Krahn et al. (1999). Data for the Canadian and Greenland animals were taken from Muir et al. (1990b) and Stern et al. (1994). As these data were generated over a period of about 10 years, the question of temporal comparability arises. Recent results from across the Canadian Arctic indicate no significant change in the concentrations of PCB's, chlordane compounds, and toxaphene in beluga whale blubber over a 10-yr period (1983–94) and no change in DDT over a 20-yr period (1972–94) (Muir et al., 1999). These findings provide some confidence for comparing concentrations of persistent organic contaminants among the belugas from different locations used in this paper.

In Table 2, ∑PCB's as reported by Krahn et al. (1999) for the eastern Beaufort Sea, eastern Chukchi Sea, and Cook Inlet animals were calculated based on the procedure of Lauenstein et al. (1993) by multiplying the sum of the concen-

Figure 1.—Sampling sites for North American belugas: St. Lawrence River estuary (off map), western Greenland (Disko Bugt), Cumberland Sound (Pangnirtung), eastern Hudson Bay (Nastapoka River), western Hudson Bay (Eskimo Point and Southeast Baffin Island), Jones Sound (Grise Fjord), eastern Beaufort Sea (Mackenzie River and Point Hope), eastern Chukchi Sea (Point Lay), and Cook Inlet.

trations of the following congeners: 18, 28, 44, 52, 66, 101, 105, 118, 128, 138, 153, 170, 180, 187, 195, 206, and 209 by 2. For the other beluga locations, ∑PCB's was the sum of all congeners measured (65). Muir et al. (1990b) stated that 12 congeners accounted for >50% of the ∑PCB's in all of their samples: 52, 66, 95, 101, 99, 118, 149, 151, 153, 138, 187/182, and 180. It therefore appears that the ∑PCB's shown in Table 2 are roughly comparable for belugas for all locations. ∑Chlordanes is the sum of the concentrations of heptachlor, heptachlor epoxide, *cis*-chlordane, *trans*-chlordane, *trans*-nonachlor, *cis*-nonachlor, oxychlordane, and nonachlor III. ∑DDT is the sum of the concentrations of 2,4′-DDT, 4,4′-DDT, 2,4′-DDD, 4,4′-DDD, 2,4′-DDE, and 4,4′DDE. Data for dieldrin, hexachlorobenzene (HCB), hexachlorocylohexane (the sum of α-, β-, and γ-HCH), and mirex are presented in Table 3.

For all Alaska belugas, PCB and chlorinated pesticide concentrations were higher in males than in females. This pattern is reported routinely for marine mammals, since females are able to transfer some of their body loads to the fetus during gestation and to their young through lactation. These avenues for decreasing body loads are not avail-

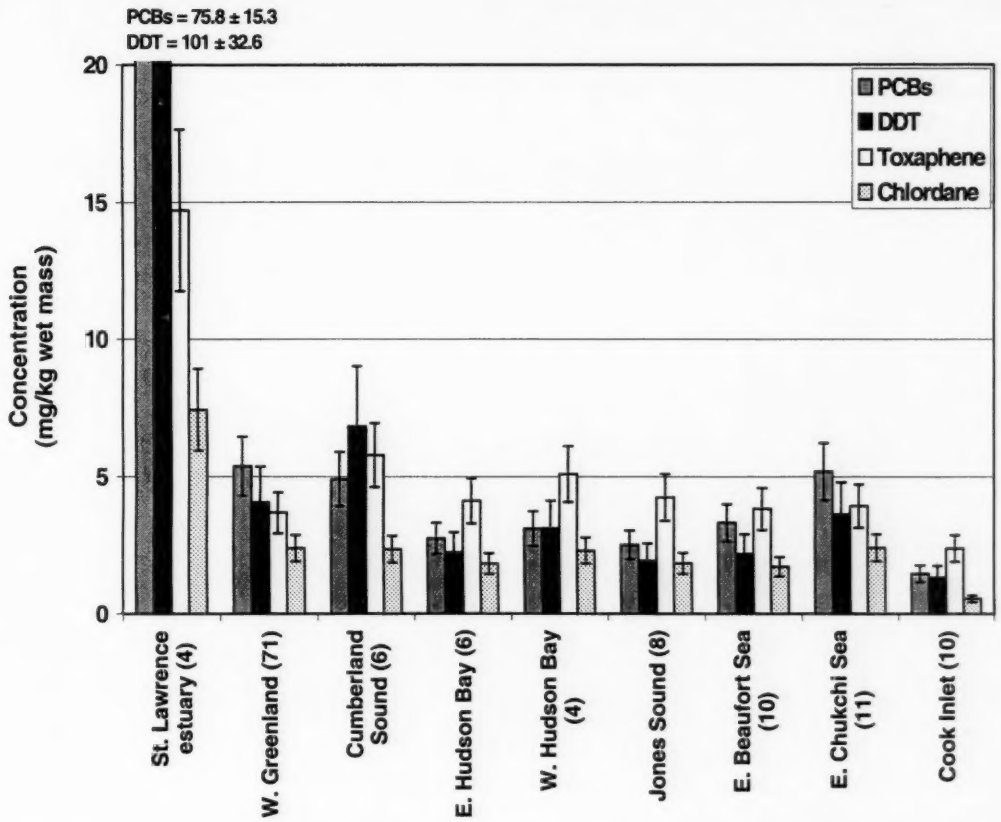

Figure 2.—Concentration (mean ±1 standard deviation) of PCB's, DDT, toxaphene, and chlordane in the blubber of male North American belugas. PCB's is ∑PCB's as described by Krahn et al. (1999) and Muir et al. (1990b). DDT is ∑DDT (sum of 2,4′-DDT, 4,4′-DDT, 2,4′-DDD, 4,4′- DDD, 2,4′-DDE, and 4,4′-DDE). Chlordane is ∑chlordane (sum of heptachlor, heptachlor epoxide, *cis*-chlordane, *trans*-chlordane, *trans*-nonachlor, *cis*-nonachlor, oxychlordane, and nonachlor III). Numbers of animals are in parentheses.

able to the males. Because males tend to have higher concentrations of these compounds in their blubber, their values may be of more concern for human consumption health issues. However, levels in females and their transfer to offspring may be of more concern to the health of the animal population.

In the case of the beluga whales shown in Table 2, the variability in blubber concentrations of PCB's and chlorinated pesticides in males was less than in females for all belugas. Thus, males were selected for comparison of these compounds among the different belugas from different locations (Fig. 2, 3). The beluga whales from the St. Lawrence estuary had the highest concentrations of these compounds, with both ∑PCB's and ∑DDT being an order of magnitude greater than the other animals and mirex being on average more than twice as great as levels reported for belugas from other locations. The higher level of mirex in the St. Lawrence estuary animals (Fig. 3) is not surprising, since the St. Lawrence River drains an area having industrial sources for this compound. In St. Lawrence estuary belugas, ∑PCB's and ∑DDT contributed much more to the total persistent organic pollutant concentrations than in either the North American Arctic animals or Cook Inlet animals (Fig. 4). On average, these two groups of compounds made up 85–90% of the total blubber concentration in the St. Lawrence belugas, while contributing 40–50% in belugas from the other locations. On the other hand, toxaphene contributed a much larger fraction to the Arctic and Cook Inlet animals (20–50% on average) than was reported for the St. Lawrence estuary animals (10%).

Among the North American belugas, the Cook Inlet animals had the lowest blubber concentrations of PCB's and chlorinated pesticides (Fig. 2, 3). Krahn et al. (1999) compared both males and females from the Cook Inlet population with those from the eastern Chukchi and eastern Beaufort Sea belugas and found that the concentrations of these compounds were significantly lower in the Cook Inlet males. Although the concentrations in the Cook Inlet females appeared to be lower than those in the

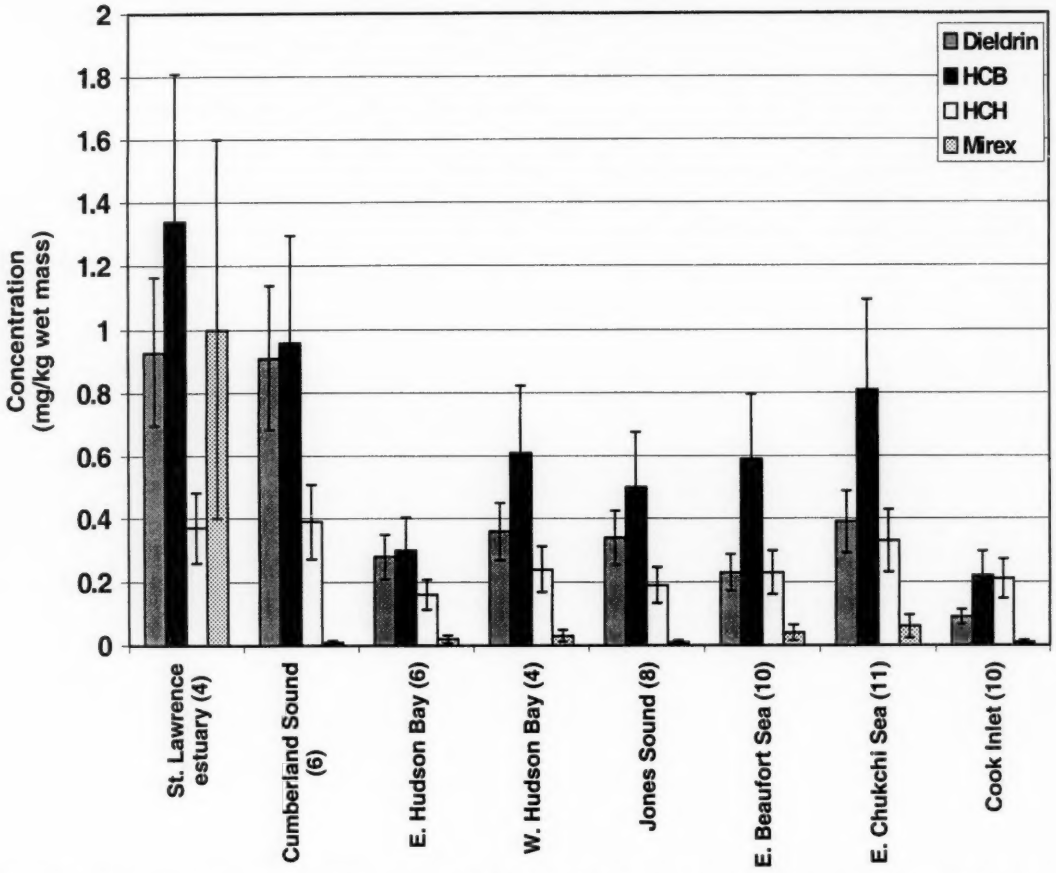

Figure 3.—Concentration (mean ±1 standard deviation) of dieldrin, HCB, HCH, and mirex in the blubber of male North American belugas. HCH is ∑HCH (sum of α-, β-, and γ-HCH). Numbers of animals are in parentheses.

eastern Chukchi Sea and eastern Beaufort Sea belugas, the differences were not statistically significant. The ratios of 4,4′-DDE to ∑DDT in the Cook Inlet animals were basically the same as those for other beluga whales in Alaska and Canada (0.47–0.57), suggesting uniform temporal exposure across the higher latitudes of North America for DDT (Krahn et al., 1999). However, concentrations of ∑chlordane were substantially lower in the Cook Inlet animals than in belugas from other locations, indicating a much lower contribution from this class of compounds to the total persistent organic contaminant loads in the Cook Inlet belugas than in the North American Arctic animals (Fig. 3, 4). Using the ratio of ∑chlordanes/∑PCB's, Krahn et al. (1999) found that the contribution of chlordane compounds to the total loads was substantially less in the Cook Inlet animals (~0.35) than in the eastern Beaufort Sea and eastern Chukchi Sea animals (~0.55), more than twice as high as for the St. Lawrence beluga whales (~0.1), and about half that for belugas from Hudson Bay and Jones Sound (~0.8). The differences in these ratios suggest different sources of these compounds, which may be related to geographic and latitudinal differences in atmospheric transport patterns and processes or different feeding habits or prey availability among these groups of belugas.

Elements

For most marine mammal species, little is known about normal concentration ranges of elements in specific tissues. Concentrations of essential elements such as zinc, copper, and selenium, and potentially toxic elements, such as cadmium and mercury, are commonly measured in liver and kidney. One must use caution comparing concentrations of specific elements in the tissues of marine mammals with those in terrestrial or freshwater species. Unlike persistent organic anthropogenic contaminants, all elements (including the potentially toxic ones) occur naturally in the earth's crust, and in many cases elevat-

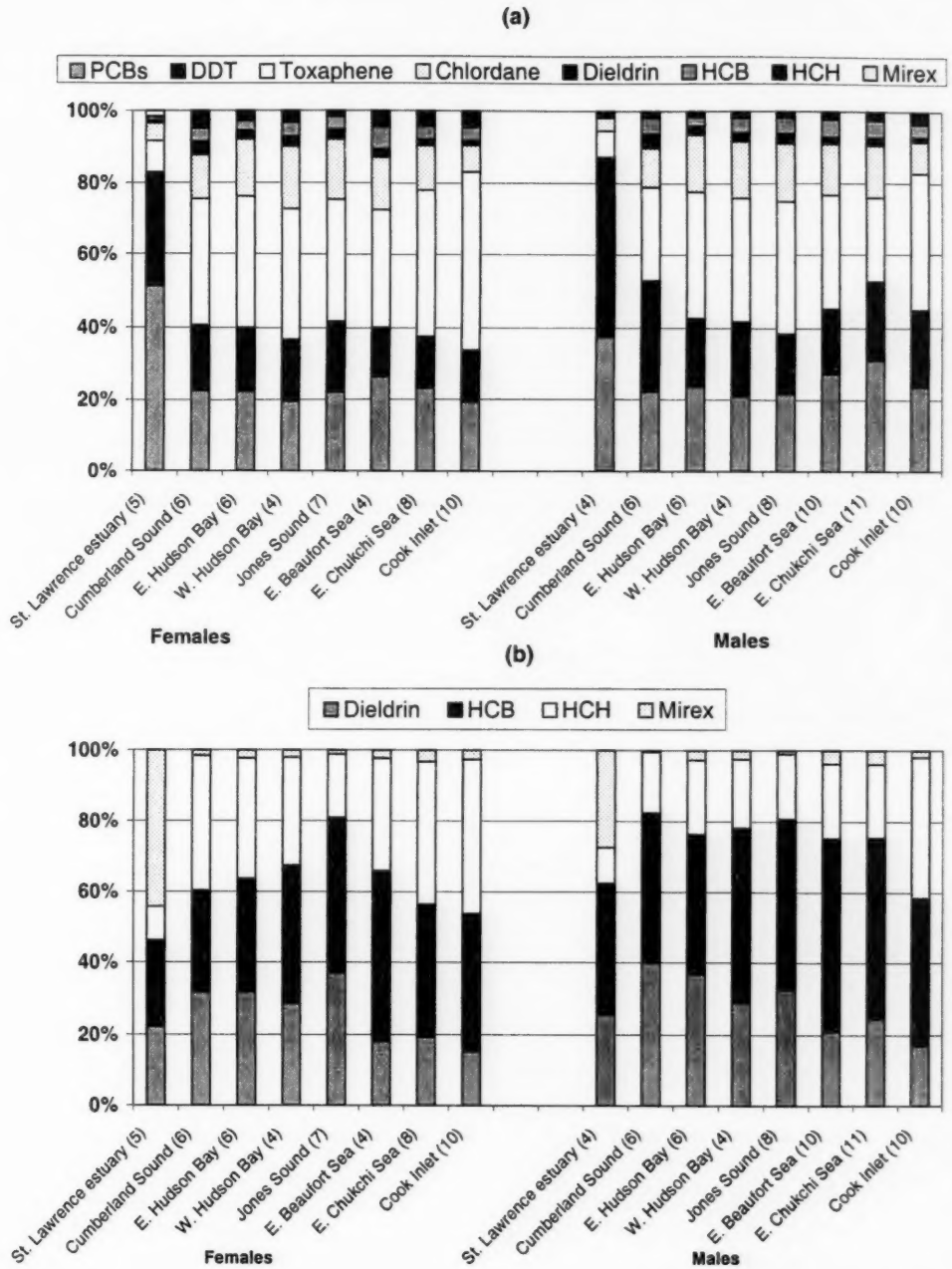

Figure 4.—Relative contributions to the persistent organic pollutant concentrations in blubber from North American belugas. PCB's is ∑PCB's as described by Krahn et al. (1999) and Muir et al. (1990b). DDT is ∑DDT (sum of 2,4′-DDT, 4,4′-DDT, 2,4′-DDD, 4,4′-DDD, 2,4′-DDE, and 4,4′-DDE). Chlordane is ∑chlordane (sum of heptachlor, heptachlor epoxide, *cis*-chlordane, *trans*-chlordane, *trans*-nonachlor, *cis*-nonachlor, oxychlordane, and nonachlor III). HCH is ∑HCH (sum of α-, β-, and γ-HCH). Numbers of animals are in parentheses.

Table 4.—Comparison of means and ranges of concentration values of selected elements measured in the livers of Alaska belugas. Values (mg/kg, wet mass) are given as mean ± 1 standard deviation. Data for the Point Hope and Point Lay animals are from Becker et al. (1995b).

	Eastern Beaufort Sea (1989) Point Hope, Alaska		Eastern Chukchi Sea Point Lay, Alaska		Cook Inlet Cook Inlet, Alaska	
Element	Males (1)	Females (3)	Males (7)	Females (3)	Males (6)	Females (4)
Na	960.5	1198 ± 145.6 1049–1340	1397 ± 150.8 1136–1576	1321 ± 176.8 1141–1494	1331 ± 191 1101–1567	1204 ± 200 983–1449
Mg	111.8	151.4 ± 70.4 78.5–219	116.9 ± 33.18 58.5–164	157.6 ± 16.10 140.5–172.5	149.8 ± 16.9 131.2–177.4	134.5 ± 26 111–162.2
Cl	1384	1481 ± 83.0 1392–1556	1814 ± 87.98 1638–1880	1684 ± 171.6 1486–1790	1610 ± 269 1312–1971	1312 ± 198 1251–1561
K	2272	2524 ± 196.2 2315–2704	2222 ± 486.9 1523–2700	1754 ± 601.9 1326–2442	2898 ± 310.8 2552–3306	2849 ± 322 2516–3021
Ca	30.82	26.3 ± 0.878 25.30–26.92	31.64 ± 10.55 20.5–44	32.7 ± 7.145 28.5–40.95	41.6 ± 6.46 34.7–50.3	26.7 ± 2.91 24–30.95
V	0.034	0.079 ± 0.026 0.049–0.095	0.1644 ± 0.063 0.037–0.205	0.1529 ± 0.1092 0.0898–0.279	0.041 ± 0.012 0.021–0.054	0.034 ± 0.022 0.015–0.065
Mn	2.506	3.211 ± 0.134 3.093–3.357	1.939 ± 0.313 1.62–2.4	1.918 ± 0.2812 1.656–2.215	2.17 ± 0.33 1.70–2.52	2.651 ± 0.72 1.617–3.254
Fe	587.5	457.3 ± 143.6 362.5–622.5	599 ± 92.95 474.5–726	558.2 ± 224.3 332–780.5	316.9 ± 116.7 228.0–494.5	235.0 ± 149.0 100.0–443.0
Co	0.011	0.1 ± 0.06 0.01–0.18	0.012 ± 0.002 0.008–0.015	0.015 ± 0.006 0.008–0.021	0.009 ± 0.002 0.006–0.012	0.0281 ± 0.041 0.005–0.0895
Cu	12.36	12.86 ± 1.336 12–14.40	12.66 ± 6.449 6.85–26.4	21.18 ± 17.43 7.1–40.68	48.93 ± 39.79 15.62–123.8	29.26 ± 20.09 3.97–48.27
Zn	22.62	33.67 ± 4.324 30.24–38.53	23.86 ± 2.758 21.1–28.65	23.68 ± 2.62 20.90–26.1	27.26 ± 2.265 24.56–30.64	24.38 ± 1.591 22.66–26.07
As	0.177	0.215 ± 0.046 0.163–0.252	0.160 ± 0.203 0.065–0.616	0.180 ± 0.020 0.162–0.201	0.078 ± 0.023 <0.05–0.120	0.356 ± 0.329 <0.07–0.815
Se	6.243	8.472 ± 5.261 3.961–14.25	18.55 ± 8.770 7.01–29.36	37.33 ± 33.07 18.20–75.51	4.347 ± 1.561 2.907–6.088	2.620 ± 1.547 1.078–4.215
Br	25.62	24.36 (n = 1)	20.45 ± 1.704 18.36–23.06	25.31 ± 9.373 17.22–35.58	17.83 ± 4.26 13.17–22.48	17.28 ± 7.321 10.22–25.00
Rb		1.346 (n = 2) 1.174–1.518	1.050 ± 0.463 0.09–1.493	1.717 (n = 1)	1.765 ± 0.267 1.372–2.084	1.387 ± 0.174 1.222–1.602
Ag	14.58	20.83 ± 8.538 14.36–30.51	24.32 ± 10.65 14.38–40.69	46.62 ± 52.98 10.05–107.4	6.778 ± 4.169 1.513–11.61	4.383 ± 4.463 0.637–9.787
Cd	0.75	1.307 ± 0.745 0.455–1.840	1.884 ± 0.438 1.14–2.41	3.333 ± 0.501 2.755–3.645	<1 <0.44–<1	0.63 ± 0.155 <0.5–0.74
Cs	0.021	0.038 ± 0.007 0.031–0.038	0.028 ± 0.003 0.024–0.033	0.033 ± 0.003 0.030–0.035	0.051 ± 0.024 0.009–0.075	0.0644 ± 0.0094 0.0556–0.0746
Hg	3.52	5.462 ± 4.428 1.397–10.18	36.53 ± 16.81[1] 17.73–50.14	52.64 ± 22.86 27.85–72.9	5.454 ± 3.471 2.98–11.42	2.568 ± 1.816 0.704–5.03
Me-Hg	0.49	0.513 ± 0.231 0.37–0.78	1.517 ± 0.592[1] 0.86–2.01	1.153 ± 0.395 0.85–1.6	1.47 ± 0.66 0.800–2.11	0.52 ± 0.25 0.34–0.70

[1] n = 3

ed tissue levels in marine animals may reflect natural geochemical and biological food web processes rather than anthropogenic sources. This is not to say that anthropogenic contamination of the marine environment by heavy metals and metalloids does not occur. They do occur, but the identification of contamination and the source of this contamination is much more difficult with heavy metals than with the persistent organic contaminants, since all of the latter are anthropogenic in origin.

The concentrations of 19 elements and methylmercury measured in the livers of 10 Cook Inlet belugas are presented and compared in Table 4 with data published on belugas sampled by AMMTAP from Point Hope and Point Lay, Alaska (Becker et al. 1995b). In addition, liver concentrations of copper, cadmium, mercury, selenium, and zinc in these animals are compared in Table 5 with published data from west Greenland (Dietz et al., 1990; Hansen et al., 1990) and six locations in Canada (Wagemann et al., 1990; Wagemann et al., 1996). The values reported from Canada (the largest database) are based on dry mass concentrations. Therefore, for direct comparison with these published values, the wet mass concentrations of these five elements in the Alaska animals were converted to dry mass values using percent moisture data for each individual sample. The conversion factors of wet mass to dry mass for the Cook Inlet and

Table 5.—Concentrations of Cu, Cd, Hg, Se, and Zn in livers of Cook Inlet belugas compared with that reported for belugas from other North American locations. Values (mg/kg dry mass) are given as mean ± 1 standard deviation.

Location (Date)	n	Age (yr)	Cu	Cd	Hg	Se	Zn	Ref.[1]
West Greenland (1980-87)	40		not analyzed	8.84 (median)	10.5 ± 13.0[2]	14.8 (median)	114 (median)	1, 2
Cumberland S., Pangnirtung (1984)	11	11.2 ± 3.7	60.7 ± 36.0	23.5 ± 23.9	18.7 ± 16.8	10.31 ± 5.57	101 ± 25.9	3
St. Lawrence estuary (1982–86)	30	17.4 ± 8.5	37.3 ± 34.5	0.58 ± 0.41	126 ±161	79.2 ± 110	98.4 ±41.8	3
E. Hudson Bay, Nastapoka R. (1984)	15	13.2 ± 7.7	150 ± 200	18.9 ± 9.88	38.4 ± 48	16.7 ± 7.97	93.2 ± 9.99	3
W. Hudson Bay, Eskimo Pt (1984)	23	11.2 ± 6.7	117 ± 250	25.0 ± 22.9	24.9 ± 25.2	15.7 ± 8.78	90.4 ± 31.4	3
W. Hudson Bay, S.E. Baffin I. (1984–94)	139	11.9 ± 6.0	76.8 ± 131	26.0 ± 19.5	33.6 ± 33.0	21.4 ± 12.7	115 ± 32.2	4
Jones Sound, Grise Fjord (1984)	17	5.6 ± 4.8	39.1 ± 21.1	12.2 ± 14.1	8.27 ± 7.71	9.21 ± 4.74	93.6 ± 18.8	3
E. Beaufort, Mackenzie R. (1981, 84)	43	13.9 ± 5.5	50.3 ± 49.0	8.52 ± 5.42	44.1 ± 45.5[3]	23.3 ±19.7	92.0 ± 15.5	3
E. Beaufort, Mackenzie R. (1993–94)	77	19.3 ± 6.6	45.2 ± 28.4	9.08 ± 4.16	108 ± 98.8	75.2 ± 55.6	112 ± 20.0	4
E. Beaufort, Point Hope, AK (1989)	4	7.0 ± 2.5	48.0 ± 6.08	4.47 ± 2.50	18.8 ± 13.0	30.0 ± 15.0	120 ± 29.6	3
E. Chukchi Sea, Point Lay, AK (1990)	10	14.1 ± 6.8[4]	61.6 ± 42.3	9.38 ± 3.39	179 ± 78.6[5]	97.2 ± 76.7	96.0 ± 11.5	5
Cook Inlet, AK (1992–95)	10	9.6 ± 3.7[6]	162 ± 130	2.39[7]	16.3 ± 13.0	14.3 ± 7.0	102 ±10.7	6

[1] 1 = Dietz et al. (1990); 2 = Hansen et al. (1990); 3 = Wagemann et al. (1990); 4 = Wagemann et al. (1996); 5 = Becker et al. (1995b); 6 = NIST (this paper).
[2] n = 6.
[3] n = 42.
[4] n = 2.
[5] n = 6.
[6] n = 8.
[7] Value based on n = 2; all other measures were below detection, ranging from <0.44 to <1mg/kg.

Point Hope animals were 0.26 ± 0.02 (mean ± 1 SE) and for the Point Lay animals was 0.25 ± 0.01. The data from west Greenland was converted from wet mass to dry mass basis using the conversion factor of 0.25. Since the west Greenland and Canadian papers do not differentiate concentrations in males and females, the data presented in Table 5 represent both genders.

As in the case of the persistent organic contaminants, these regional comparisons use data generated over a decade. Recent studies by Wagemann et al. (1996) indicate that, at least for the eastern Canadian Arctic, there has been little change in the concentrations of cadmium in beluga livers from 1981 to 1994; however, hepatic mercury concentrations were significantly higher in both the eastern Canadian animals and the western (eastern Beaufort Sea) from 1993 to 1994, than from 1981 to 1984. Wagemann et al. (1996) also suggested there was a higher rate of mercury accumulation recently than was the case 15 years before.

Elements that are essential for normal health of animals are well regulated metabolically. One would, therefore, expect little variation in the concentration levels of these elements among individual animals and among populations. For example, the hepatic zinc concentrations among the Alaska belugas vary by 11–25% from the average values. Nonessential elements are not usually regulated metabolically and may bioaccumulate and/or biomagnify. The concentration levels of these elements vary to a greater extent among individual animals and among populations. For example hepatic mercury concentrations of the Alaska belugas span more than an order of magnitude.

Mercury and cadmium are two heavy metals that bioaccumulate, and high concentrations may result in toxic effects to an animal. Cadmium can accumulate to high levels in both kidney and liver of birds and mammals. Cadmium concentrations in the kidneys are usually 3–4 times higher than in the liver of marine mammals. Hammond and Beliles (1980) state that in humans at low doses, kidney concentrations are about ten times higher than liver concentrations, and that with increasing levels of exposure the concentration ratio approaches one. Among Alaska marine mammals, high concentrations of cadmium in livers and kidneys have been reported for both bowhead whale, *Balaena mysticetus* (Krone et al., 1999), and walrus, *Odobenus rosmarus* (Taylor et al., 1989), and probably reflect both biomagnification through the food web and accumulation with increasing age of the animals. As compared to many other marine mammal species, cadmium concentrations are usually relatively low in belugas. In fact, the lowest levels reported for belugas were those found in the St. Lawrence estuary animals (Fig. 5), which are considered to be highly contaminated with anthropogenic pollutants. The concentrations of cadmium in the livers of the Alaska animals are relatively low as compared with those reported for belugas from Hudson Bay and Cumberland Sound in Canada, but similar to those reported for belugas from Greenland and Jones Sound, Canada (Table 5). The lowest hepatic cadmium concentrations were found in the animals from Cook Inlet, where concentrations ranged from the detection limit of <0.44 to 0.74 mg/kg wet mass (Table 4). Kidney concentrations ranged from 2.16 to 8.99 mg/kg wet mass (mean ±1 standard deviation = 3.98 ± 2.08 mg/kg wet mass).

Unlike cadmium, mercury is present at relatively high concentrations in the livers of belugas throughout North America. These levels are quite similar to those reported for Atlantic pilot whales, *Globicephalus melas* (Meador et al., 1993; Becker et al., 1995b; Mackey et al., 1995). Among the Alaska animals, the mean concentration of mercury in livers of the Cook Inlet animals was an order of magnitude lower than that reported recently for the eastern Beaufort Sea and eastern Chukchi Sea animals (significant at the 99% confidence level) (Table 5, Fig. 6a). Compared with most other belugas in North America, hepatic mercury levels in the Cook Inlet animals were at the low end of the range of values and similar to those reported for animals from Greenland and Cumberland Sound, Canada.

The mercury values shown in Tables 4 and 5 are for total mercury, which includes both inorganic and organic forms of this element. The toxic form of this element is methylmercury, which for animals with high total mercury concentrations in livers, usually contributes a relatively small fraction to the total concentration in this organ (Fig. 7a). Although the hepatic total mercury levels were lowest in the Cook Inlet animals, concentrations of methylmercury were similar among all of the Alaska animals. Concentrations in the Cook Inlet belugas ranged from 0.09 mg/kg wet mass in a fetus to 2.11 mg/kg wet mass in a large male (median levels were 0.5 mg/kg wet mass for females and 1.5 mg/kg wet mass for males). Dietz et al. (1990), in their study of belugas and narwhals, *Monodon monoceros*, from western Greenland, found that for total mercury hepatic concentrations of <1 mg/kg wet mass, about half of the mercury was organic and it did not exceed 2.2 mg/kg wet mass even with hepatic total mercury concentrations 50 times greater. The hepatic concentrations in the fetus and the large male from Cook Inlet (0.09–2.11 mg/kg wet mass) represent the largest range of methylmercury values found to date in Alaska belugas.

Marine mammals are exposed to methylmercury through their prey (particularly fish). There is some evidence to support the idea that marine mammals are able to metabolically convert the methylmercury consumed to the relatively nontoxic inorganic mercury that is then stored in the liver. If that is the case, over time the inorganic fraction of the hepatic mercury would be expected to increase, but the methylmercury fraction would not. Methylmercury values for the Alaska belugas generally do not exceed 2 mg/kg wet mass at the highest levels of total mercury (i.e. up to 73 ppm total mercury), and the highest percentage of methylmercury occurs at the low end of the total mercury range. The relationship of percent methylmercury with total hepatic mercury shown in Figure 7b for all of the Alaska belugas supports this hypothesis and suggests that a threshold concentration level may exist, above which methylmercury no longer accumulates in this organ.

The pattern of relative differences in selenium concentrations reported in liver

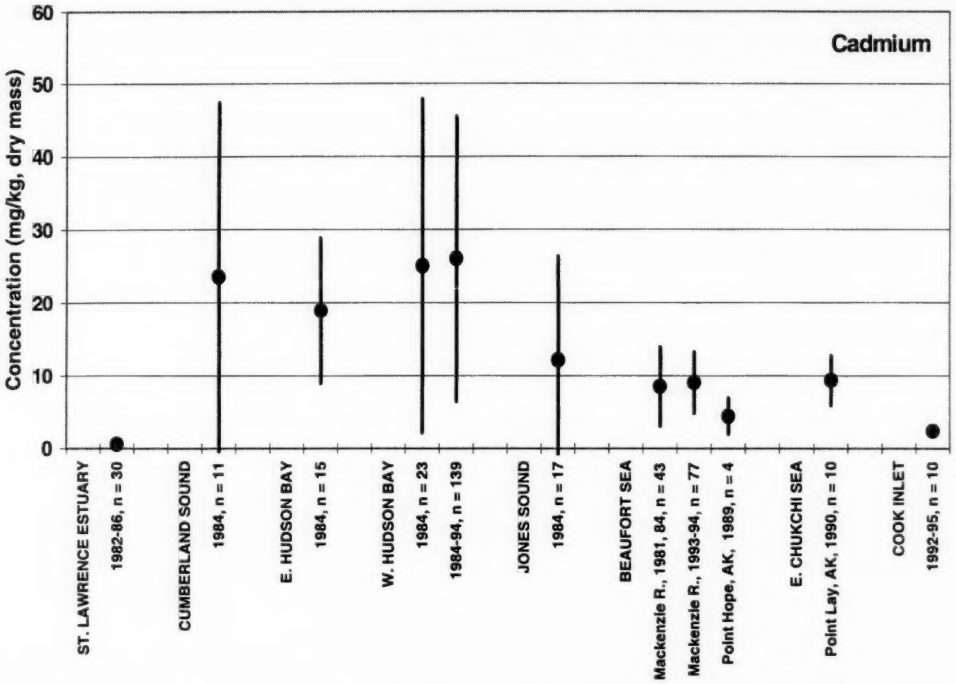

Figure 5.—Concentration of cadmium (mean ±1 standard deviation) in liver tissue of Cook Inlet beluga whales compared to concentrations reported in the livers of other North American populations and stocks of this species. The standard deviation for each mean (●) is indicated by a vertical bar. Geographic locations, dates of sample collections, and numbers of animals are shown on the X axis. Animals from the Mackenzie River and Point Hope are thought to be from the eastern Beaufort Sea stock. Data are from Wagemann et al. (1990), Wagemann et al. (1996), Becker et al. (1995b), and NIST (this paper).

tissue among the North American belugas is similar to that of total mercury (Fig. 6). The positive correlation of concentrations of selenium with mercury in liver tissue has been commonly reported for many species of animals (e.g. Koeman et al., 1973; Wagemann et al., 1983; Julshamn et al., 1987; Muir et al., 1988b; Meador et al., 1993; Mackey et al., 1995). In vertebrates this correlation has been shown for kidney as well as liver. This selenium-mercury relationship is thought to be indicative of both an accumulative and a protective function for the organism by incorporating the mercury within an innocuous complex involving selenium compounds and metal-binding proteins (Hammond and Beliles, 1980).

Selenium was positively correlated with mercury concentrations in liver and kidney tissue of the Cook Inlet belugas as well as the livers of the eastern Beaufort Sea and eastern Chukchi Sea animals. Regression plots of hepatic mercury concentrations versus hepatic selenium concentrations for all of the Alaska belugas yield a linear correlation coefficient (R^2) value of 0.73 (for N = 18).

Although silver is not usually measured in vertebrate tissues, it is one of the 37 elements routinely measured in liver specimens banked by the AMMTAP. Becker et al. (1995a) reported silver concentrations in the livers of eastern Beaufort Sea and eastern Chukchi Sea belugas that are from one to three orders of magnitude higher than what has been reported for other marine mammal species. The silver concentrations were positively correlated with mercury concentrations, selenium concentrations, and with ages of the animals. A linear relationship between hepatic silver and selenium concentrations also has been observed for several other marine mammal species, although hepatic concentrations of silver in other species are much lower (Mackey et al., 1996). This relationship remains when the silver and selenium concentrations for the Cook Inlet animals are added to the Alaska beluga whale database; in fact, the correlation between silver and selenium is much stronger than for mercury and selenium. Regression plots of hepatic silver concentrations versus hepatic selenium concentrations for all of the Alaska belugas yield a linear correlation coefficient (R^2) value of 0.93 (for N = 21).

Physiochemical processes that may be involved in the accumulation and possible interaction of selenium, mercury, and silver in beluga whale livers have been described elsewhere (Becker et al., 1995a; Mackey et al., 1996). Including the silver data for the Cook Inlet animals in the comparison of beluga whales with other marine mammal species supports the pattern of high levels of this element in the liver tissue of beluga

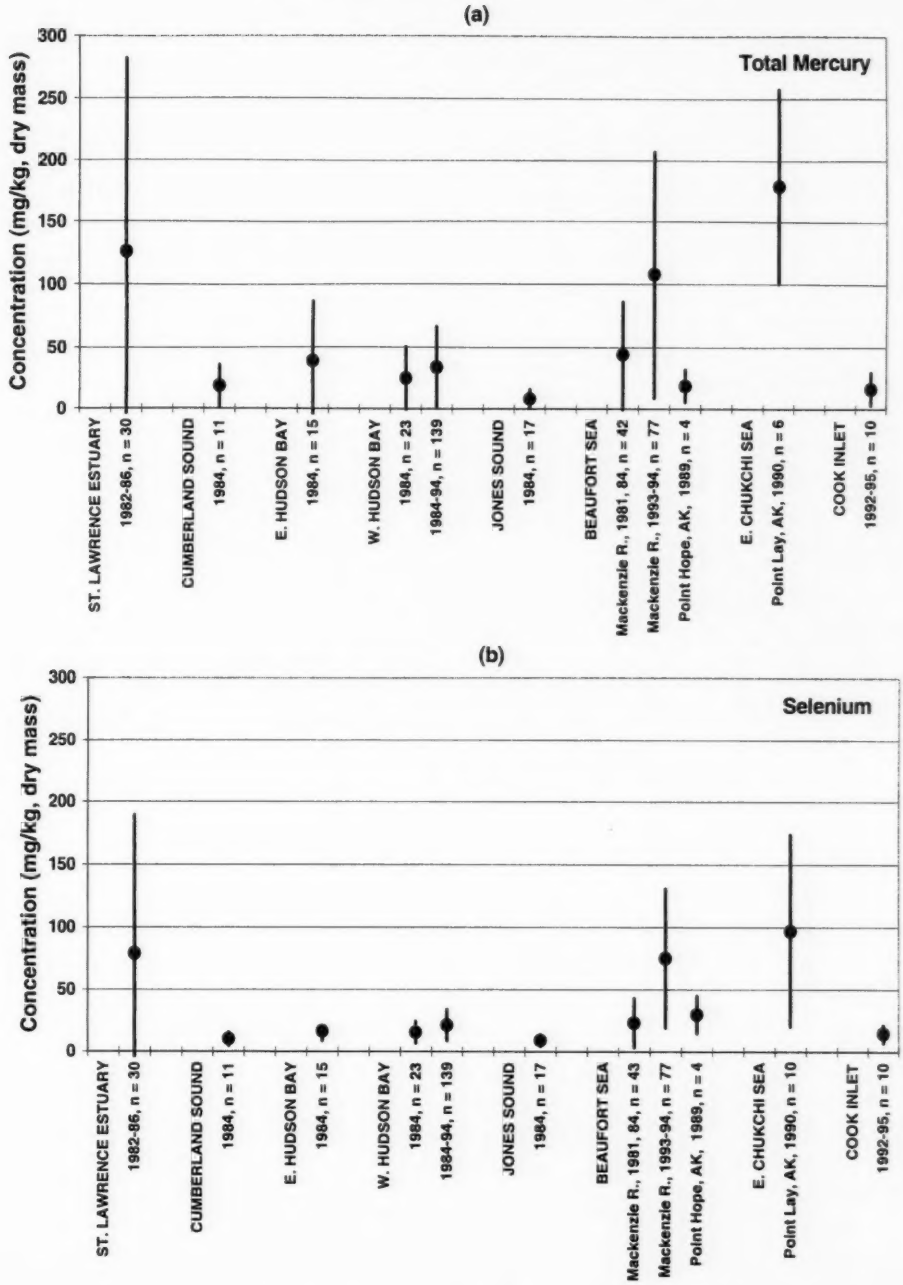

Figure 6.—Concentration of mercury and selenium (mean ±1 standard deviation) in liver tissue of Cook Inlet beluga whales compared to concentrations reported in the livers of other North American populations and stocks of this species. The standard deviation for each mean (●) is indicated by a vertical bar. Geographic locations, dates of sample collections, and numbers of animals are shown on the X axis. Animals from the Mackenzie River and Point Hope are thought to be from the eastern Beaufort Sea stock. Data are from Wagemann et al. (1990), Wagemann et al. (1996), Becker et al. (1995b), and NIST (this paper).

whales. Although the concentrations in the Cook Inlet animals (1.52–11.61 mg/kg wet mass) were significantly less than those reported previously for the eastern Beaufort Sea and eastern Chukchi Sea animals (10.05 to 107.4 mg/kg wet mass), the Cook Inlet beluga whales still had much higher levels than those reported for other marine mammal species (0.01–1.50 mg/kg wet mass) (Becker et al., 1997). These results suggest that the high levels of silver in

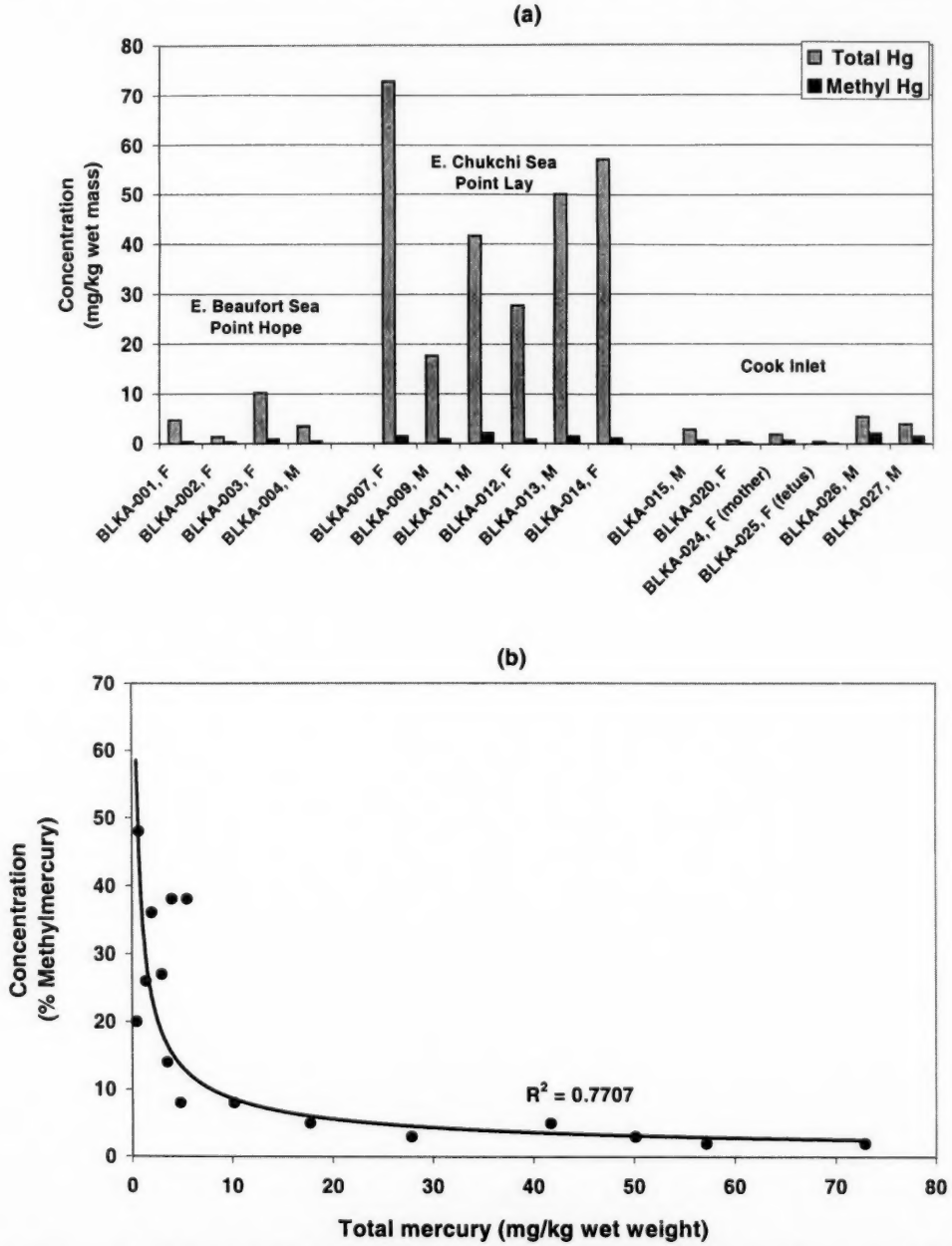

Figure 7.—Mercury in liver tissue of belugas. (a) Concentration of total mercury and methyl mercury in liver tissue of Cook Inlet belugas compared to the Point Hope and Point Lay animals. (b) Relationship between methylmercury and total mercury for beluga liver tissue from all three locations. The data is from Becker et al. (1995b) and NIST (this paper).

livers of beluga whales is a species-specific phenomenon and not a geographic phenomenon; however, data for belugas from other locations, including those from eastern Canada and Greenland, are necessary to determine if this is true.

Copper was present in higher concentrations in the livers of Cook Inlet animals than in the other Alaska animals (Table 4). When compared to the eastern Beaufort Sea and eastern Chukchi Sea belugas, concentrations were on average 2–3 times higher in the Cook Inlet animals (significant at the 95% confidence level). The relatively high average concentration and the high variability of the hepatic copper in the Cook Inlet belugas were similar to what has been reported for belugas from Hudson Bay (Table 5, Fig. 8).

Mackey et al. (1996) reported higher concentrations of vanadium in livers of Alaska marine mammals as compared with marine mammals from U.S. east coast. In the latter case, vanadium concentrations were at or below detection limits (<0.01 mg/kg), while in the livers of Alaska marine mammals, concentrations ranged from 0.02 mg/kg to 3.8 mg/kg wet mass. The highest concentrations were reported by Warburton and Seagars (1993) for walrus (0.25–3.8 mg/kg wet mass), while the lowest were reported by Mackey et al. (1996) for belugas (0.3–1.9 mg/kg wet mass). Vanadium concentrations in livers of the Cook Inlet belugas (Table 4) were the lowest of the Alaska animals (0.021–0.065 mg/kg wet mass), but still substantially higher than what has been reported from the lower latitudes of the United States (Mackey et al., 1996). Mackey et al. (1996), in their discussion of this apparent pattern of higher hepatic vanadium concentrations in marine mammals of the higher latitudes of Alaska, suggest that this may reflect a unique dietary source, a unique geochemical source of this element, or anthropogenic input to the Alaska marine environment. In any case, there is no evidence to indicate that the levels found so far in the Alaska animals pose any health hazard to the animals or to human consumers of these tissues.

Comparison of Cook Inlet Belugas with Belugas From Other Locations

Although occurring in what one might consider a region under substantially more anthropogenic influence than belugas from other locations in Alaska, the Cook Inlet animals had lower concentrations of PCB's and chlorinated pesticides than have been reported for other Alaska belugas or for this species from other areas of North America. Although one might suggest that differences be-

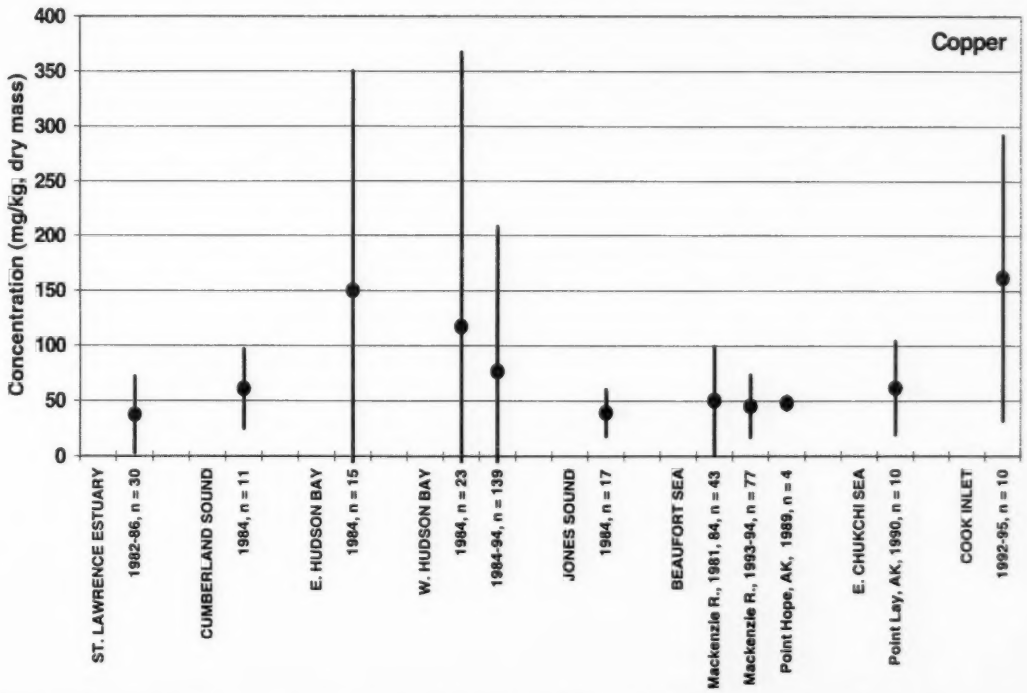

Figure 8.—Concentration of copper (mean ±1 standard deviation) in liver tissue of Cook Inlet beluga whales compared to concentrations reported in the livers of other North American populations and stocks of this species. The standard deviation for each mean (●) is indicated by a vertical bar. Geographic locations, dates of sample collections, and numbers of animals are shown on the X axis. Animals from the Mackenzie River and Point Hope are thought to be from the eastern Beaufort Sea stock. Data are from Wagemann et al. (1990), Wagemann et al. (1996), Becker et al. (1995b), and NIST (this paper).

tween the ages of the Cook Inlet animals and those of the other belugas might be a factor in these concentration differences, there are other differences that suggest that other factors may also be involved. Krahn et al. (1999), using principal components analysis, were able to demonstrate clear pattern differences in individual PCB and chlorinated pesticide analytes between the blubber of the Cook Inlet animals and that of the eastern Chukchi Sea animals. Chlordane compounds also contributed less to the organochlorine contaminant loads of the Cook Inlet animals than for the other North American belugas.

In addition to having relatively low concentrations of persistent organic contaminants in their blubber, the Cook Inlet belugas also had relatively low levels of mercury, selenium, and cadmium in their livers relative to other North American belugas (Table 4) and relatively low levels of silver and vanadium relative to the eastern Beaufort Sea and eastern Chukchi Sea animals (Table 5). Mackey et al. (1996) reported a positive correlation of liver concentrations of all five of these elements with increasing age in belugas. However, only a few of the Cook Inlet animals had known ages, and inclusion of the limited age values for this population to the data for the eastern Chukchi Sea and the eastern Beaufort Sea animals did not result in a significant correlation of any of the elements with age.

In comparison with the other Alaska belugas, the Cook Inlet belugas were also unique in having relatively high hepatic copper concentrations. The toxicological implication of these levels is unknown. Copper, being an essential element, is regulated metabolically in vertebrates and tends to vary among and within species. Diet and age appear to be important factors in accumulation of this element. McClurg (1984) suggested that the relatively high levels of copper in the liver of Ross seals from Antarctica were a reflection of the naturally higher levels of this element in its principal prey, squid. Prey difference might also be a factor in the hepatic copper concentration differences between the Cook Inlet and other Alaska belugas. Copper apparently does not accumulate with age, and, in fact, the highest copper concentrations are usually found in the younger animals. Wagemann et al. (1983) reported that copper concentration was negatively correlated with length for narwhals, and Honda et al. (1983) found the same for striped dolphin, *Stenella coeruleoalba*. However, the limited age data for the Cook Inlet belugas do not allow for an evaluation of age as the determining factor for the relatively high hepatic copper concentration in this population.

Compared with other belugas, the Cook Inlet animals appear to have unique patterns of persistent organic contaminants and elements in their tissues. Such differences for the Cook Inlet animals suggest different sources of these compounds, which may be related to geographic and latitudinal differences in atmospheric transport patterns and processes, geochemical source differences, or different feeding habits or prey availability for these animals.

Human Health Issues

Although lipophilic contaminants such as PCB's and chlorinated pesticides have been found to be generally lower in Arctic Alaska marine mammals than in marine mammals from lower latitudes, the levels in these Arctic animals are of special significance since they provide food for human residents whose diets are relatively high in fat. The beluga may therefore be of particular significance, since it has the potential for concentrating lipophilic compounds in its blubber at relatively high levels. Among the elements measured in the liver and kidney of the Cook Inlet belugas, only mercury would appear to be of any concern to human health. However, liver and kidney of belugas are not usually consumed as subsistence foods. Of more direct concern are the concentrations of the PCB's and chlorinated pesticides in the blubber and their potential health risk to consumers of maktaaq.

Among most of the marine mammals used as a subsistence food in Alaska (i.e. ringed seal, bearded seal, walrus, and bowhead whale), the beluga has relatively high concentrations of persistent organic contaminants in the blubber. Therefore, the consumption of the maktaaq of this species might be of particular concern for long-term human health effects.

Krahn et al. (1999) in their discussion of the persistent organochlorine contaminants found in the Cook Inlet, eastern Beaufort Sea, and eastern Chukchi Sea belugas calculated the allowable dose of contaminants in blubber based on the Allowable Daily Intake (ADI) levels recommended by the Contaminants Toxicology Section, Food Directorate, Health Canada, as described by Jensen et al. (1997). These calculations were based on the ADI of individual compounds (or groups of compounds such as ∑PCB's), the average body weight for an adult human (70 kg), and the mean tissue concentration in mg/kg wet mass. The ADI represents a life-long daily exposure and a significant safety factor has been applied to make these safe and conservative estimates. The ADI also reflects the relative toxicity of the compound. For example, the ADI of ∑PCB's is 1.0, while for ∑chlordane the ADI is 0.05. Their results indicate that the limiting compound for the Cook Inlet beluga whales is toxaphene with blubber consumption rate limit of 7 g/day.

For the eastern Beaufort Sea and eastern Chukchi Sea animals, the limiting compound was found to be chlordane at a recommended daily consumption rate less than half of that for the Cook Inlet animals. Such differences between the Cook Inlet animals and the other belugas reflect both the lower levels of all persistent organic contaminants in the Cook Inlet belugas and the lesser contribution of ∑chlordane to this population.

These calculations should also be viewed with caution. They are useful for comparative purposes among populations of animals; however, they do not provide sufficient information upon which to base dietary advice. Although providing some idea of relative risk from individual compounds and relative differences in these risks among species, the actual health effects from consumption of these compounds intermittently or constantly over a period of time, remain unknown. Potential risks must

also be evaluated relative to the known nutritional benefits of consumption of food derived from marine mammal tissues. It is imperative that other known benefits of subsistence use (cultural, economic, nutritional, and overall health) enter into the risk management equation. Discussions of these issues are provided by Kinloch et al. (1992) and Egeland et al. (1998).

Conclusions

The Cook Inlet belugas had much lower concentrations of PCB's and chlorinated pesticides than those which have been reported for belugas from Point Hope and Mackenzie River (eastern Beaufort Sea animals) and Point Lay (eastern Chukchi Sea animals). As compared to the other persistent organic contaminants, Σchlordane contributed substantially less to the total burden of the compounds in the Cook Inlet belugas than it did to the burden of any of the other belugas. This suggests that there is a different source (geographic or food web) of these compounds for the Cook Inlet belugas. The concentrations of persistent organic contaminants in the Cook Inlet males were higher than in the females from this population; however, the relative difference was much less than for the eastern Beaufort Sea and eastern Chukchi Sea animals.

Also, in the case of heavy metals and other elements, cadmium, mercury, and selenium were much lower in the livers of Cook Inlet animals than all other belugas, and vanadium and silver were lower in the Cook Inlet belugas than in the other Arctic Alaska belugas. Hepatic methylmercury levels were similar to those reported for other beluga whales and did not exceed 2.11 mg/kg wet mass. The silver, selenium, and mercury relationship previously described for other belugas and pilot whales was also found in the Cook Inlet population. The relatively high hepatic concentration of silver, described previously for the eastern Chukchi Sea and eastern Beaufort Sea belugas was also found in the Cook Inlet animals, suggesting a species-specific phenomenon.

An initial estimate of the human health risk associated with the consumption of beluga blubber (based on the Allowable Daily Intake levels recommended by Health Canada) suggested that the principal chemical limiting the recommended consumption rate of Cook Inlet blubber was toxaphene. This was different from the eastern Beaufort Sea and eastern Chukchi Sea belugas, where the limiting compound was chlordane. In the case of all Alaska belugas (including those from Cook Inlet), additional and more thorough evaluation of potential health effects relative to the known health benefits of marine mammal derived food is required to provide adequate and more scientific-based recommendations on human consumption.

Due to the lower concentrations in the Cook Inlet belugas, the effects of PCB's and chlorinated pesticides on animal health may be of less significance for the Cook Inlet animals than for belugas from other locations. However, very little is known about the role that multiple stressors play in the health of individual animals and populations. Biotoxins, bacterial or viral infections, parasitic disease, physical stresses in the environment, periodic limitations in food, or stress of being hunted in combination with the accumulation of toxic chemicals may further compromise animal health. The interaction of such stressors on a declining population, such as the Cook Inlet belugas, and the resulting effects on population recruitment should be a major avenue of future research and evaluation.

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Application of Suction-cup-attached VHF Transmitters to the Study of Beluga, *Delphinapterus leucas*, Surfacing Behavior in Cook Inlet, Alaska

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Introduction

Aerial surveys of belugas, *Delphinapterus leucas*, were conducted in Cook Inlet, Alaska, during June–July from 1993 to 2000 (Rugh et al., 2000) by the NMFS National Marine Mammal Laboratory (NMML), in cooperation with the Alaska Regional Office, the Alaska Beluga Whale Committee, and the Cook Inlet Marine Mammal Council (CIMMC). Counts from these surveys have been used to establish an abundance estimate for this stock (Hobbs et al., 2000a). Survey counts must be corrected for the fraction of whales that are not visible to aerial observers during the counting period, which varies from a few seconds to more than 20 sec during a systematic aerial pass (Hobbs et al., 2000b). The waters of upper Cook Inlet are extremely turbid, with typical Secchi disk readings of less than 20 cm (Moore et al., 2000; Shelden and Angliss[1]). Thus, submerged whales are not visible to aerial observers. Statistics on the dive interval (time between the midpoints of contiguous surfacings) and surfacing interval (the time a whale is visible at the surface per surfacing) are, therefore, necessary to determine this correction factor (Hobbs et al., 2000b).

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[1] Shelden, K. E. W., and R. P. Angliss. 1995. Characterization of beluga whale (*Delphinapterus leucas*) habitat through oceanographic sampling of the Susitna River delta in Cook Inlet, Alaska, 11–18 June 1994. Int. Whal. Comm. Unpubl. Doc. SC/47/SM13, 10 p.

ABSTRACT—Suction-cup-attached VHF radio transmitters were deployed on belugas, Delphinapterus leucas, *in Cook Inlet, Alaska, in 1994 and 1995 to characterize the whales' surfacing behavior. Data from video recordings were also used to characterize behavior of undisturbed whales and whales actively pursued for tagging. Statistics for dive intervals (time between the midpoints of contiguous surfacings) and surfacing intervals (time at the surface per surfacing) were estimated. Operations took place on the tidal delta of the Susitna and Little Susitna Rivers. During the 2-yr study, eight whales were successfully tagged, five tags remained attached for >60 min, and data from these were used in the analyses. Mean dive interval was 24.1 sec (interwhale SD=6.4 sec, n=5). The mean surfacing interval, as determined from the duration of signals received from the radio transmitters, was 1.8 sec (SD=0.3 sec, n=125) for one of the whales. Videotaped behaviors were categorized as "head-lifts" or "slow-rolls." Belugas were more likely to head-lift than to slow-roll during vessel approaches and tagging attempts when compared to undisturbed whales. In undisturbed groups, surfacing intervals determined from video records were significantly different between head-lifting ($\bar{x}$=1.02 sec, SD=0.38 sec, n=28) and slow-rolling whales ($\bar{x}$ =2.45 sec, SD=0.37 sec, n=106). Undisturbed juveniles exhibited shorter slow-roll surfacing intervals ($\bar{x}$=2.25 sec, SD=0.32 sec, n=36) than adults ($\bar{x}$=2.55 sec, SD=0.36 sec, n=70). We did not observe strong reactions by the belugas to the suction-cup tags. This tagging method shows promise for obtaining surfacing data for durations of several days.*

VHF radio-tagging studies were conducted in 1983 on belugas in Bristol Bay, Alaska (Frost et al., 1985), to obtain data on the diving characteristics of those whales. In that study, the instrument pack was pinned through the whales' dorsal ridge. Like the whales of upper Cook Inlet, the tagged Bristol Bay belugas were found around extensive tidal mud flats in extremely turbid water. Sergeant (1981) made shore-based measurements of durations of dives and surfacings of belugas in very turbid waters near the mouth of the Churchill River, Manitoba, Canada. Behavioral differences between the Bristol Bay, Churchill River, and Cook Inlet stocks, however, are not known. Further, the diving behavior of any particular stock may change seasonally and geographically. It is, therefore, important to obtain dive data that is representative of the whales being surveyed by the aerial observers.

To ensure that this occurred, the NMML conducted similar tagging studies on the whales at the Susitna River delta (Fig. 1) concurrently with the 1994 and 1995 aerial surveys. This is the region of Cook Inlet in which the majority of whales have been sighted during aerial surveys (Rugh et al., 2000). Our goal was to characterize the diving behavior of belugas found on the Susitna River delta, and to estimate dive interval and surfacing interval statistics to correct aerial survey abundance estimates. The transmitters were attached using suction-cup tags, also referred to as remora tags.

This type of tag has been used for the attachment of instrument packs onto wild cetaceans by several investigators, with a minimum amount of harassment

to the animals and no permanent scarring. Although strong responses (including rapid swimming and energetic leaps from the water) to suction-cup tags by bottlenose dolphins, *Tursiops truncatus,* in Doubtful Sound, New Zealand, made this particular method unfeasible there (Schneider et al., 1998), tag attachment on killer whales, *Orcinus orca* (Baird,

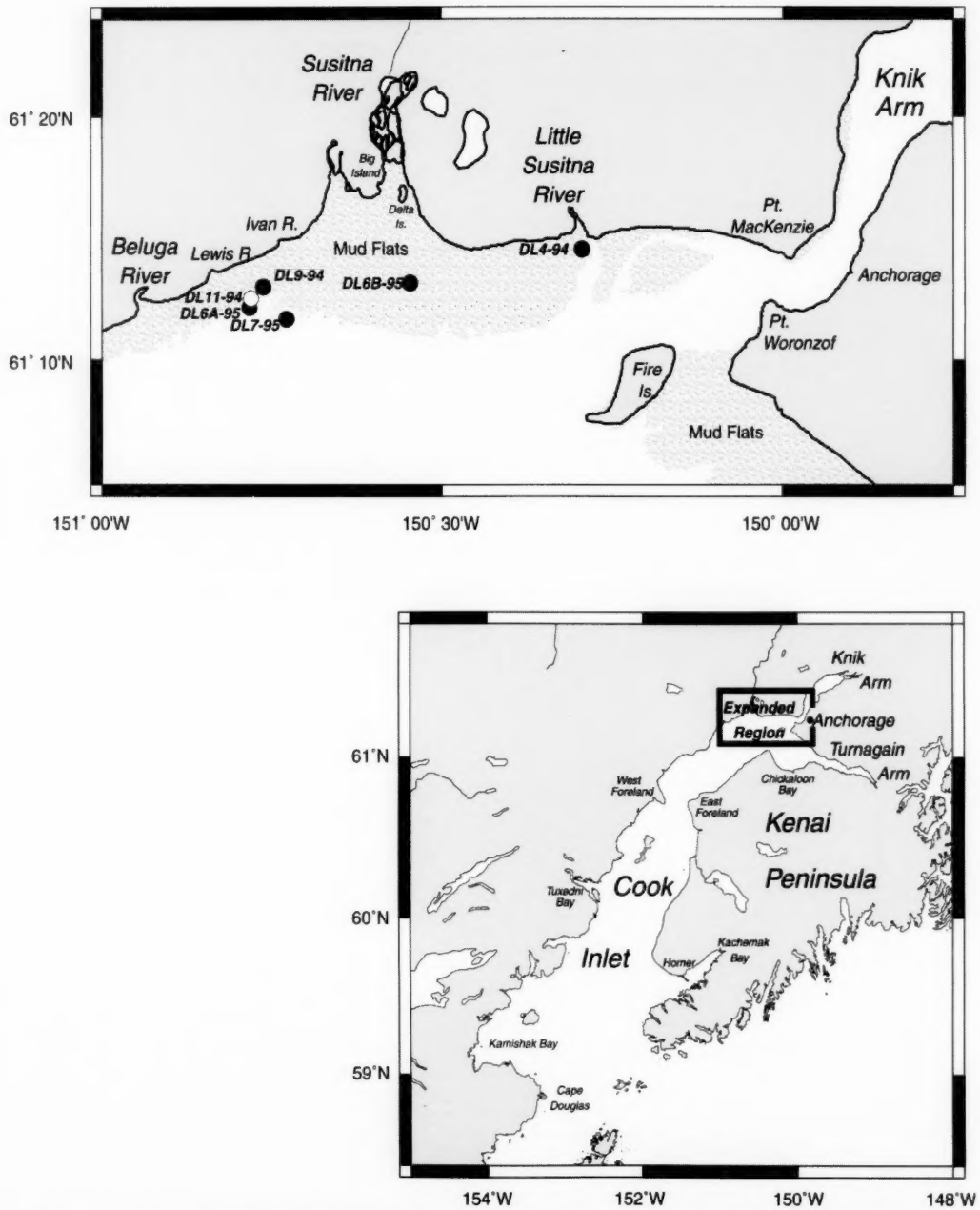


Figure 1.—The study site for tagging belugas in Cook Inlet, Alaska, in 1994 and 1995. Dots mark the tagging locations of five whales from which surfacing statistics were estimated. The circle marks the tagging location of the whale for which only video data were obtained (tag fell off after about 5 min).

1994; Baird and Goodyear[2]; Baird et al.[3]), and several baleen whale species (humpback whales, *Megaptera novaeangliae*: Goodyear, 1989; fin whales, *Balaenoptera physalus*: Giard et al.[4]; and gray whales, *Eschrichtius robustus*: Malcolm et al., 1996) resulted in little or no observable reactions. Low to moderate reactions by Dall's porpoise, *Phocoenoides dalli*, were observed during the first several minutes after tag deployment (Hanson and Baird, 1998; Hanson et al.[5]). While, for Hector's dolphins, *Cephalorhynchus hectori*, such reactions were observed 40 min after tag deployment (Stone et al., 1994, 1998). Suction-cup tags have been continuously deployed for as long as 80 h on humpback whales (Goodyear, 1989; Goodyear[6]), 78 h on fin whales (Giard and Michaud, 1997) and 31 h on killer whales (Baird, 1998).

Methods

The suction-cup tags used in this study were designed by Cetacean Research Technology[7], Seattle, Wash. (Fig. 2). Closed-cell foam (not shown in Fig. 2) was used to make the tags positively buoyant. Upon being released from the whale, the transmitter and tag could be recovered and reused. A water-soluble gelatinous plug placed into a small hole in the transmitter mount provided a time-release mechanism for the tags so the tag could be recovered the same day. Suction was broken when this plug dissolved. In a controlled laboratory environment, suction was maintained for 10–14 h when a gelatinous plug about 4 mm thick was used. The VHF radio transmitter (model 5A, Advanced Telemetry Systems, Inc., Isanti, Minn.) frequencies ranged between 164 and 168 MHz with a power output of 6 milliwatts (6 V × 1 mA). Pulses were transmitted at a rate of 400/min and had a nominal width of 20 ms. The high pulse rate was chosen so that the duration of surfacing intervals could be easily resolved. The total weight of the tag, including transmitter, suction cup, and floatation material, was about 185 g. Tags were deployed by using a telescoping (2.5–5 m long) aluminum pole (shown in Fig. 3a–f) equipped with plastic clips that lightly gripped the cylindrical housing of the transmitter. Once suction was made between the tag and the whale, the tag was easily released from the clips by pulling the pole away from the whale.

The suction-cup portions of the tags were tested on captive belugas at the Point Defiance Zoo, Tacoma, Wash., on 5 May 1994. Tags were placed just left of the dorsal ridge of two whales (a 900 kg male and a 450 kg female). The whales were then sent through their training ex-

[2] Baird, R. W., and J. D. Goodyear. 1993. An examination of killer whale diving behavior using a recoverable, suction-cup attached TDR/VHF tag. *In* Tenth Biennial Conf. Biol. Mar. Mammals, Galveston, Texas, 11–15 November (Soc. Mar. Mammal.), p. 25 (abstr.).

[3] Baird, R. W., L. M. Dill, and M. B. Hanson. 1998. Diving behaviour of killer whales. *In* World Mar. Mammal Sci. Conf., Monaco, 20–24 Jan. (Soc. Mar. Mammal. and European Cetacean Soc.), p. 9 (abstr.).

[4] Giard, J., R. Michaud, and J. D. Goodyear. 1998. The days and nights of fin whales: a VHF tracking study of their behavior and use of habitat in the St. Lawrence Estuary, Canada. *In* World Mar. Mammal Sci. Conf., Monaco, 20–24 Jan. (Soc. Mar. Mammal. and European Cetacean Soc.), p. 53 (abstr.).

[5] Hanson, M. B., R. W. Baird, and R. L. DeLong. 1998. Short-term movements and dive behavior of tagged Dall's porpoise in Haro Strait, Washington. *In* World Mar. Mammal Sci. Conf., Monaco, 20–24 Jan. (Soc. Mar. Mammal. and European Cetacean Soc.), p. 59–60 (abstr.).

[6] Goodyear, J. D. 1981. "Remora" tag effects the first radio tracking of an Atlantic humpback. *In* Fourth Biennial Conf. Biol. Mar. Mammals, San Francisco, Calif., 14–18 December (Soc. Mar. Mammal. and European Cetacean Soc.), p. 46 (abstr.).

[7] Reference to trade names or commercial firms does not indicate endorsement by the National Marine Fisheries Service.

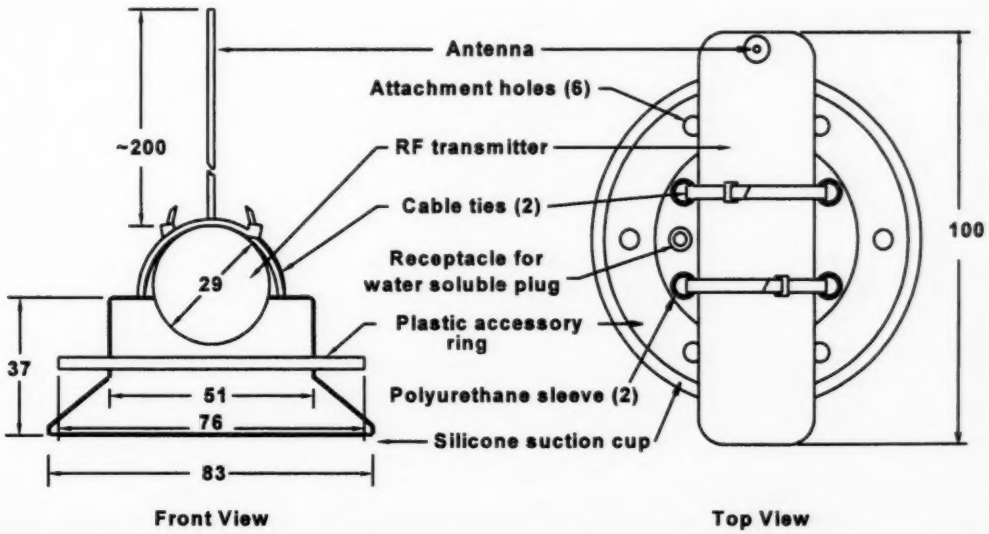
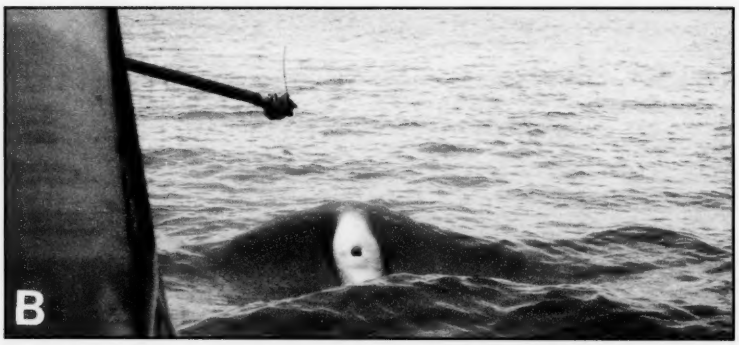


Figure 2.—Schematic of suction-cup tag and VHF transmitter. The closed-cell foam used for floatation is not shown. All dimensions are in millimeters.



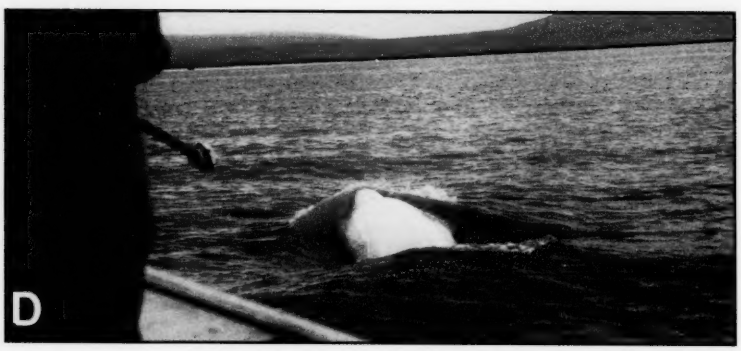


Figure 3.—Tagging belugas in Cook Inlet, Alaska. A. wakes generated by a beluga swimming rapidly in water <2 m deep (the first wake is created by the animals head, the second wake by the flukes). The tag deployment pole has the tag attached to the end. B. whale head appears in the first wake (blowhole visible). C. the whale's back appears and the animal begins to D. slow-roll, exposing its back. Photographs by Janice M. Waite.

ercises which included rapid swimming around the tank, rapid and extensive flexing of the back, and breaching. Both tags remained attached to the whales during the exercises and were removed by the trainer after being on the male for 2.25 h and the female for 1.75 h. Minimal tag slippage (~10 cm) was evident on the male. Examination of the belugas at the site of tag attachment revealed small depressions where the tag had been in contact with the skin. These indentations were no longer visible an hour after removal.

Small-boat surveys and tagging operations were conducted in the northeastern portion of Cook Inlet during 1–22 June 1994 and 3–7 August 1995. The focal region was the Susitna River delta located about 35 km west of Anchorage (Fig. 1). During both years, tagging operations were conducted from either a 5 m rigid-hulled inflatable boat or a 6 m aluminum boat.

The first three survey days (1–3 June) of the 1994 field study were spent developing tag deployment methods. On the fourth survey day, a local beluga hunter (D. Owens) joined the team and provided training in beluga pursuit techniques. Tagging was typically conducted just after low tide. Local beluga hunters have determined that it is easiest to track the whales when they are in water <2m deep. There, whales generate wakes and circular upwellings or "footprints" on the surface as their rostrum pushes through the water and flukes undulate rapidly (Fig. 3a).

Tagging bouts consisted of an approach on a group, isolation of an individual, and pursuit. A maximum of three tagging attempts were made on an individual. The pursuit vessel was driven rapidly toward the edge of the group,

Figure 3 cont.—E. a member of the tagging team attempts to attach the tag. F. the tag is attached successfully, releasing from the pole as it is pulled away from the whale. G. tag attached to whale DL7-95. Photographs E, F by Janice M. Waite; photograph G by James A. Lerczak.

and a whale was chosen by its proximity to the vessel and its consistency in creating wakes. Isolation of an individual occurred within seconds and was either due to the individual moving away from the group or to the group distancing itself from the tagging operation. If it surfaced for a breath within 2 m of the boat, tag attachment was attempted by one or two members of the tagging crew positioned in the bow of the boat (Fig. 3e–f). Efforts were made to place the tag midway down the length of the whale and about 10–20 cm on either side of the dorsal ridge (Fig. 3g). Photographs and videotape were used to document tag location, whale size and coloration, tag placement, and to corroborate signals from the radio transmitter.

Radio-tag surfacing data were recorded by two methods. One of the tagging team members monitored the audio output of the radio receiver with a headset, while the rest of the team attempted to maintain visual contact with the beluga group containing the tagged whale. Initially, an observer announced surfacings to ensure that the audio monitor was interpreting the audio signal correctly. The time of each surfacing was recorded in real-time in a logbook. The audio signals from the receiver were simultaneously recorded on a standard audio cassette tape. Tagged whales were monitored from a distance of 0.5 to 2 km using a radio receiver and a whip antenna placed 2–4 m above the deck of the boat. When strong signals were received, the boat was allowed to drift with the engines off. If the signals were weak, the motor was restarted, and the boat was directed slowly toward the group until the signal strengthened. A hand-held directional antenna connected to a second radio receiver was used to aid in the relocation of a tagged whale and to find tags after they had fallen off a whale.

Blocks of data from the logbooks and tapes were used in the analyses if the surfacing signals could clearly be distinguished from the background noise. Blocks of time in which surfacing signals were low in intensity relative to background (probably because the boat was too far from the tagged whale) were not used. To reduce the bias towards shorter dive intervals, a minimum period of 10 min was chosen so that at least several long dives were included in a block. Within acceptable blocks of time, surfacings were designated as either definite or questionable. Signals from definite surfacings were high in intensity and long in duration (about 1–2 sec). Questionable surfacings were generally low in intensity and short in duration (<0.5 sec). Similar short, sporadic signals were occasionally heard during tests when the transmitter was known to be submerged. A dive interval was defined as the time from the

middle of one surfacing to the middle of the next. The times of surfacings from audio tapes were digitized with a computer programmed to record computer times when a keyboard key was struck by a tape reviewer upon hearing a surfacing signal. Separate keys were used to distinguish definite from questionable surfacings. Surfacing intervals were measured using two keyboard keys to mark the beginning and end of the signal from each surfacing. For this, the tape playback speed was reduced to the lowest speed allowed by the tape deck to minimize the response time error of the tape reviewer with respect to the signal length. Tapes were digitized independently by two reviewers as a test of consistency.

The data collected in 1994 were analyzed using two criteria: with both definite and questionable surfacings included (Type A) or with only definite surfacings (Type B). In this way, the significance of the questionable surfacings could be assessed. Few questionable surfacings occurred in the data from 1995, and only time blocks with definite surfacings were used. We estimated the mean dive interval, μ, as the average of the mean dive intervals, μ_i, obtained from the N tagged whales. When μ is used in a correction of a count, it is necessary to estimate the inter-whale variance of the mean dive interval, σ_1^2, and the variance of the dive interval distribution of individual whales, σ_2^2. We assumed that individuals are independent in their diving behavior, and these variances were estimated by:

$$\sigma_1^2 = \frac{1}{N-1}\sum(\mu_i - \mu)^2$$

$$\sigma_2^2 = \frac{1}{N}\sum\sigma_i^2,$$

where σ_i^2 is the variance of the dive interval distribution of each tagged whale.

To assess the impact of the tagging bouts on subsequent dive intervals and to determine whether there was a trend in dive interval with time since tagging, data from whales tagged in 1995 were divided into at least two 30-min blocks after tagging, and the first 30 min were further subdivided into 10-min blocks. The mean and standard deviation of dive intervals were calculated separately for each of these blocks and for the period of time when the whales were followed to obtain photographs.

Video recorded surfacing behaviors collected prior to approaching beluga groups and during tagging pursuits were classified as "slow-rolls" or "head-lifts." During a slow-roll surfacing (Fig. 3d, f, g), the whale's head appeared then receded followed by the surfacing of the back, which first appeared as a thin line on the surface before arching high out of the water as the whale dove. The flukes were rarely observed breaking the surface. During a head-lift (Fig. 3b, c), only the head appeared above the surface then receded. In the analysis, whales observed slow-rolling were categorized as either juveniles or adults. These age classes were distinguished based on coloration, juveniles being uniformly gray and adults uniformly white. It was too difficult to determine the color of individuals displaying head-lift surfacing behaviors (i.e. the visual cue was small and video image resolution was poor during stop action). Therefore, head-lifts of juveniles and adults were pooled. To determine how regularly the head-lift behavior was exhibited by undisturbed whales, slowly panned video segments of undisturbed whales were used, and a random sample of surfacings were analyzed.

Results

Whale responses to our vessel activity followed a typical pattern during most of our tagging attempts. Once the vessel approached within about 10 m of a group, the whales moved away rapidly, creating wakes. During these initial rapid approaches on groups, before an individual whale was isolated for a tagging attempt, the fleeing whales were more likely to head-lift (92%) than slow-roll (8%; n=25 video recordings in 1994). The initial burst of speed by the whales at the start of each tagging bout lasted for only a short duration (<2 min). The whales then slowed and surfaced more frequently. At the termination of a tagging bout, whether or not a tag was attached, the whale that was isolated usually moved away from the vessel without slow-rolling at the surface until it was >10 m away from the vessel. The whale returned to the beluga group within about 15 min after the pursuit was terminated. Though not quantified, these behaviors were substantiated by field observations in both years.

An interesting behavior displayed by whales evading the tagging vessel was to rest at the bottom for several minutes, giving no cues to their location. Apparently, this evasion technique is most frequently used by older whales who have experience with hunters.[8] Whale DL6B-95 (Table 1) used this technique when we pursued it. On two occasions, we stopped the pursuit boat, cut the engines, and waited at the location where we thought the whale was resting. After about 2 min, the whale surfaced within 2–3 m of the vessel, and our pursuit continued.

Despite our presence, and the occasional presence of hunters in the area, the belugas never left the immediate survey area during the study. Whales in the vicinity of our tagging operations would move 300–500 m away during pursuits. Once the pursuit vessel stopped approaching, whales would return to within 100 m of the vessel within about 15 min. When boat engines were off, whales surfaced as close as 5 m and approached within 2 m or went under the vessels as evidenced by bubbles, "footprints" at the surface, or as indicated by the depth sounder. Prior to mid June, belugas were found in large clumped groups (>50) often surfacing in multiple directions. After mid June, the whales were more dispersed in groups ranging from 1–20 individuals. In August, the whales were dispersed for the duration of the tagging operations, consistent with previous observations of the dispersal of large groups by mid summer (Rugh et al., 2000).

Between 3 and 17 June 1994, a total of 93 individual belugas were isolated for tagging. Only 4 of the 93 attempts resulted in successful deployments of

[8] D. Owens (beluga hunter and CIMMC Chairman), Box 102456, Anchorage, AK 99510. Personal commun., July 1995.

Table 1.—Summary of six tagging events of belugas in Cook Inlet, Alaska, in 1994 and 1995.

Tagged beluga identification	Date and time of tag deployment	Location	Whale description	Tag position on whale	Time range of data collection (time after tagging)		Reason for termination of data collection
					Beginning (min)	Ending (min)	
DL4-94	4 June 1994 14:05	lat. 61° 14.6′ N long. 150° 17.6′ W	Small, young adult; completely white	Dorsal surface of caudal area	148	412	Foul weather; tag still attached to whale. Tag found by local fisherman.
DL9-94	9 June 1994 15:55	lat. 61° 13.0′ N long. 150° 45.7′ W	Small, young adult; white with some gray mottling.	5 cm lateral to centerline of back; in line with dorsal ridge	10	132	Foul weather; tag still attached to whale. Tag was not recovered.
DL11-94	11 June 1994 12:48	lat. 61° 12.5′ N long. 150° 46.8′ W	Adult; white with slightly grayish mottling.	10 cm lateral to centerline of back; in line with dorsal ridge	0	5	Tag detached while whale was still in view of tagging vessel. Only video data collected.
DL6A-95	6 August 1995 09:14	lat. 61° 12.1′ N long. 150° 46.9′ W	Juvenile; uniformly light gray.	30-50 cm left of centerline of back; 15 cm forward of dorsal ridge	2	75	Whale swam out of range of receiver. Tag found floating in the delta 2.25 h after deployment.
DL6B-95	6 August 1995 13:13	lat. 61° 13.2′ N long. 150° 32.8′ W	Large adult; uniformly white.	30-50 cm left of centerline of back; in line with dorsal ridge	1	68	Tag detached from whale and was recovered within a few min after detachment.
DL7-95	7 August 1995 10:01	lat. 61° 11.7′ N long. 150° 43.7′ W	Large adult; uniformly white.	15 cm left of centerline of back; 15-30 cm forward of dorsal ridge	1	64	Whale swam out of range of receiver. Tag was not recovered.

tags. The successful attempts captured on videotape took an average of 5.5 min (SD=2.9 min, n=3). The reason for aborting was clear in 40 of the 47 recorded failed attempts. The greatest percentage of failures (38%) was due to the whale entering deep water (>2 m in depth). This resulted in the wake collapsing, leaving the tagging team with no visual cue of the whale's location.

The second highest failure rate (22%) was due to poor attachment of the tag. Tags would dislodge prematurely from the deployment pole after coming into contact with the whale at an improper angle or if the pole tip dipped into the water while underway. Other reasons included: aborting the attempt because the whale was too small or an adult was accompanied by a calf (10%); aborting the attempt after three unsuccessful approaches had been made (10%); unable to stay with a whale because it was too evasive (8%); the whale was lost in low contrast lighting (8%); or the wake of the boat was confused with the wake of the whale (5%).

Two of the four successfully deployed tags in 1994 stayed on long enough (>60 min) for surfacing data to be collected. A third tag remained attached for just over 5 min (whale DL11-94, Table 1). While no radio-transmitter data was collected from this tag, most surfacings were captured on video for the duration the tag was attached. Four whales were successfully tagged in 1995, and three radio-tags remained attached long enough for surfacing data to be collected (Table 1).

For whale DL4-94, radio contact was lost immediately after tag deployment; the tag was presumed lost, and other whale groups in the delta were pursued. After about 2.5 h, signals from DL4-94 were detected about 8.5 km to the west of the tag deployment location (Fig. 1). Surfacing data were then collected for 4.4 h using handwritten logbook entries (no audiotapes were recorded). Data collection was terminated because of foul weather, although the tag was still attached to the whale. The tag was discovered on the shore several days later by local fishermen. In contrast, data collection, using both logbook entries and tape recordings, commenced only 10 min or less after tag deployment for the other four whales. The locations of these tagging events are shown in Figure 1. Size and coloration were used as an indication of age of the tagged whales (Table 1).

For the dive interval analysis, logbook and tape-recorded records were combined to make as complete a time series as possible. Logbook data were used for periods common to both records. It was necessary to scale the dive and surfacing intervals obtained from the computer programs to account for differences in recording and playback tape speeds (even when the tape deck was run at normal speed, the playback time was shorter than the logbook time by 29 sec, on average, per 45 min of tape, or about 1%). This was accomplished by matching the surfacing times from the beginning and end of each tape side in the digitized record to the surfacing times from the logbook data to obtain the actual times for these surfacings.

The statistics μ, σ_1, and σ_2 were estimated to be 24.1 sec, 6.4 sec, and 26.6 sec, respectively (Table 2). These quantities were calculated using values from analysis Type B. Probability density histograms for dive intervals were calculated for each tagged whale and for each analysis type (Fig. 4a–f). Although much of the probability density is centered around the median dive interval, each distribution shows significant probability of long dive intervals (>2× median) which causes the means to be considerably higher than the medians.

For analysis Type B, the probability of long dive intervals increased and the mean of the dive interval distribution lengthened compared to analysis Type A (Table 2). This was quite evident for DL4-94. However, the results from the two analysis types were not very different for DL9-94, because there were few

Table 2.—Dive interval statistics for five beluga whales suction-cup tagged in Cook Inlet, Alaska in 1994 and 1995. Analysis Type A includes both definite and questionable surfacings; type B includes only definite surfacings. Logbook and tape-recorded data were combined into one time series and analyzed for all whales except DL4-94, which only had logbook data.

Whale ID and tagging date	Analysis type	Dive interval statistics					Percentile		Total time (min)	Sample size
		Median (sec)	Mean (sec)	SD (sec)	Max (sec)	Min (sec)	97.5th	2.5th		
DL4-94	A	18.0	26.8	24.7	182	4	102.5	8.0	204	460
4 June 1994	B	19.0	35.1	41.4	356	4	133.2	8.0	204	348
DL9-94	A	17.2	21.0	13.1	114.8	6.8	59.8	9.2	119	338
9 June 1994	B	17.1	23.2	20.2	164.2	6.8	88.8	9.0	118	304
DL6A-95	B	14.0	20.1	21.1	151	4	80.7	6.0	37	109
6 August 1995										
DL6B-95	B	14.0	19.2	15.5	131	6	62.7	7.0	53	166
6 August 1995										
DL7-95	B	13.0	22.9	27.0	152	7	108.4	8.0	55	143
7 August 1995										

Table 3.—Dive interval statistics for three belugas suction-cup tagged in Cook Inlet, Alaska, in 1995 (stratified by time after tagging).

Time category	Beluga identification								
	DL6A-95			DL6B-95			DL7-95		
	Mean dive Interval (sec)	SD (sec)	*n*	Mean dive interval (sec)	SD (sec)	*n*	Mean dive interval (sec)	SD (sec)	*n*
All periods of time	20.1	21.1	109	19.2	15.5	166	22.9	27.0	143
During photo operations	14.9	10.1	60	16.6	15.1	41	32.9	40.0	38
After photo operations	26.6	28.2	49	20.0	15.6	125	19.3	19.4	105
1st 10 min after tagging event	17.1	7.9	28	12.1	4.6	11	28.8	31.6	16
2nd 10 min after tagging event	12.8	11.4	33	17.2	17.8	13	30.3	38.5	21
3rd 10 min after tagging event	23.6	28.0	28	19.2	14.6	30	26.9	36.4	23
2nd half hour after tagging event	31.7	28.9	20	19.1	12.6	92	18.5	17.8	81
After 1st hour				24.4	27.2	20			

questionable surfacings. Small secondary peaks at roughly 47.5 sec and 77.5 sec in the dive interval histograms of DL4-94 (Fig. 4a, b) may be the result of tag placement (on the tail stock rather than the dorsal ridge). The first secondary peak may correspond to two actual surfacings being interpreted as one, and the second may correspond to three actual surfacings being interpreted as one.

For whales tagged in 1995, there was no clear trend in the dive intervals as a function of time since the tagging event (Table 3). Two whales showed an apparent increase in dive interval, while the other showed a possible decrease. The variation from one whale to the next was as great as the variation from one time interval to the next for an individual. Further analysis is unwarranted because of the small sample size.

To measure the surfacing interval, we used 125 tape-recorded surfacings from whale DL9-94. Distributions of surfacing intervals as determined by two independent tape reviewers are shown in Figure 5a. The distribution from reviewer 1 is slightly narrower ($\bar{x}$ =1.88 sec, SD=0.28 sec) and has a significantly higher mean than the distribution from reviewer 2 ($\bar{x}$ =1.70 sec, SD=0.33 sec) (t-test=4.6, d.f.=239, P<0.001). The surface intervals measured by the two reviewers are well correlated (Fig. 5b). A linear fit to this curve has a slope of 0.954 (SD=0.063, r^2 =0.65, F=227, d.f.=122). Although the two reviewers were able to record a relative measure of the duration of surfacing intervals, interpretations of the onset and ending of the signals were different, leading to the slight differences in the distributions.

Using video recording of undisturbed beluga groups, surfacing intervals for each color category were compared for those whales exhibiting slow-roll behavior (Fig. 5c). Juvenile belugas (gray) averaged 2.25 sec at the surface (SD=0.32 sec, n=36) while adults (white) surfaced for an average of 2.55 sec (SD=0.36 sec, n=70). Adults spent significantly more time at the surface than juveniles (t-test =4.5, d.f.=79, P<0.001). This was also evident in video recordings of an adult/calf pair. Seven complete surfacings were captured for the adult and eight for the calf (all slow-rolls). The mean surfacing interval was 2.77 sec (SD=0.22 sec) for the adult and 1.42 sec (SD=0.33 sec) for the calf. Adult/calf surfacings were not always synchronized.

Color categories were combined and averaged in order to compare slow-roll behavior to head-lift behavior (Fig. 5c). As expected, the mean surfacing interval during a head-lift ($\bar{x}$=1.02 sec, SD=0.38 sec, n=28) was significantly less than the mean surfacing interval during a slow-roll ($\bar{x}$=2.45 sec, SD=0.37 sec, n=106) (t-test=17.9, d.f.=132, P<0.001). Only 24% (n=110) of the surfacings in undisturbed groups were head-lifts. This was considerably lower than the percentage observed for whales harassed during tagging bouts.

As stated earlier, belugas in groups fleeing from approaching tagging vessels were observed to head-lift (92%) more often than slow-roll (8%). During 27 video recorded tagging pursuits, 85%

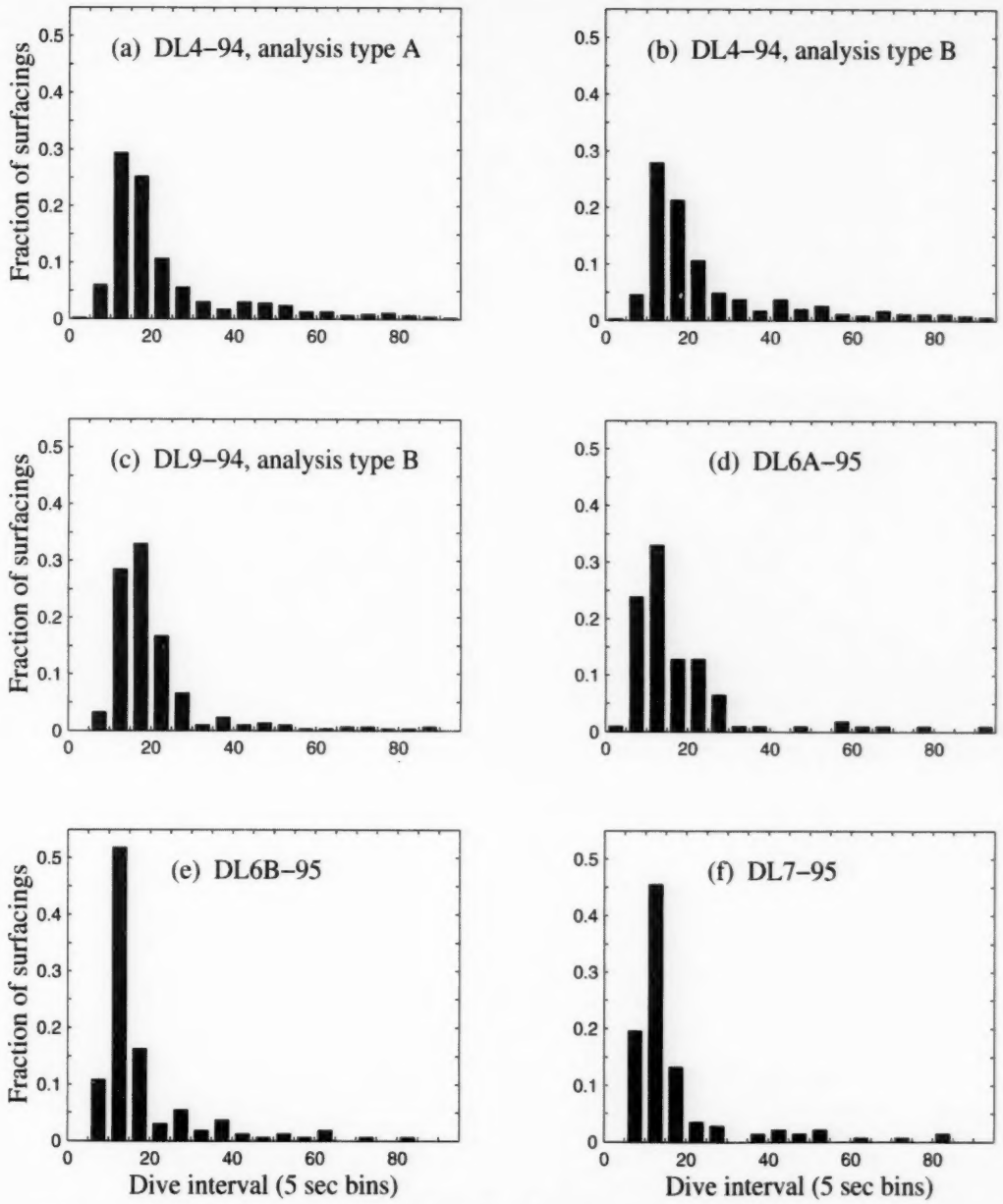


Figure 4.—Dive interval probability distributions for five tagged belugas (see Table 2 for distribution statistics). Distributions obtained from analysis types A (includes both questionable and definite surfacings) and B (definite surfacings only) are plotted for DL4-94 in (a) and (b), respectively. Only definite surfacings were used to obtain distributions for the other whales. The full extent of the long dive intervals are not shown in the plots so that the shapes of the distributions can be more easily compared.

of the whales isolated for tagging initially reacted by head-lifting on the first surfacing. Individuals isolated for tagging varied in their surfacing behavior during a chase sequence. Only 15% were observed to slow-roll thoughout the entire bout, while 59% exhibited only head-lift behavior. The remainder, 26%, exhibited almost equal preference

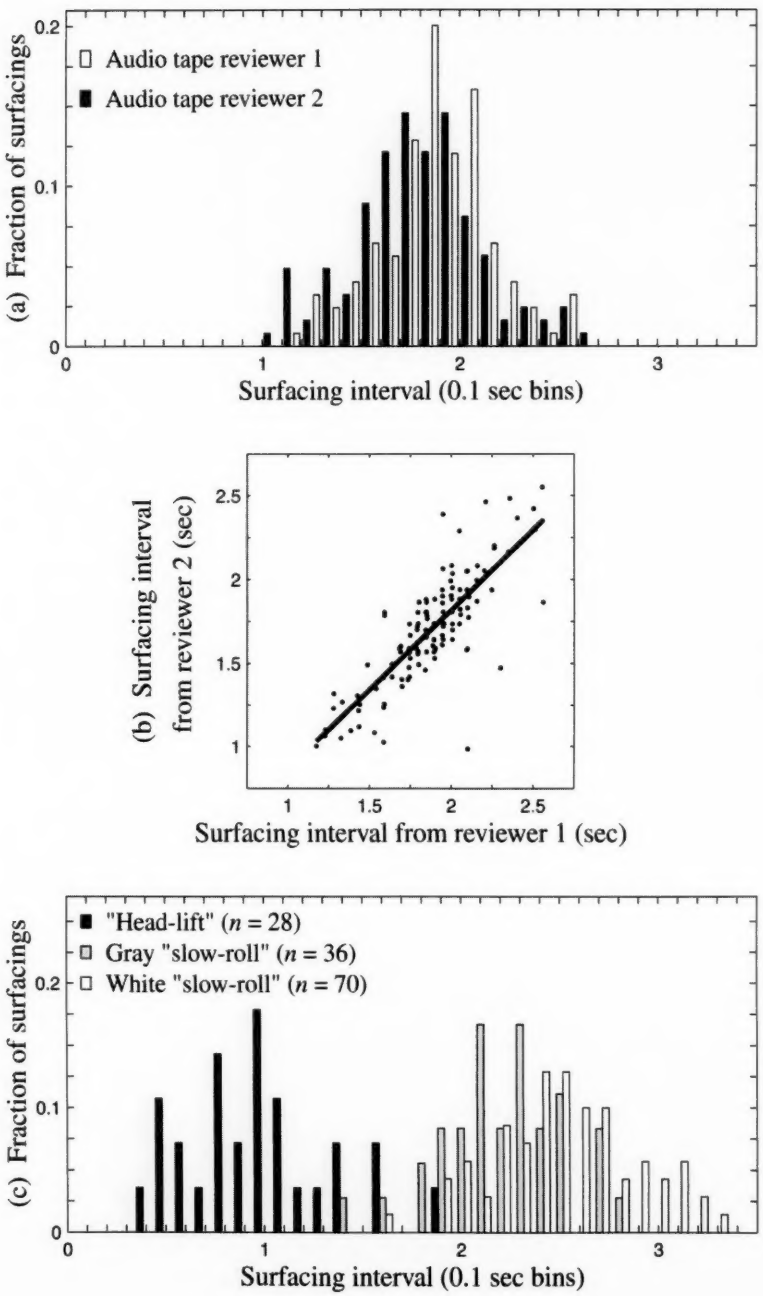

(a) Fraction of surfacings
Audio tape reviewer 1
Audio tape reviewer 2
Surfacing interval (0.1 sec bins)
(b) Surfacing interval from reviewer 2 (sec)
Surfacing interval from reviewer 1 (sec)
(c) Fraction of surfacings
"Head-lift" (n = 28)
Gray "slow-roll" (n = 36)
White "slow-roll" (n = 70)
Surfacing interval (0.1 sec bins)

Figure 5.—Probability distributions of the surfacing intervals of belugas tagged in Cook Inlet, Alaska: a) comparing two independent reviews of 125 surfacings from audio tapes of radio-tag data from DL9-94; b) the correlation of surfacing intervals estimated by the two reviews, and c) probability distributions of the surfacing intervals for undisturbed whales segregated by age and size class (juveniles (gray) vs. adult (white)) and behavioral type (head-lift vs. slow-roll) analyzed from videotapes collected in 1994.

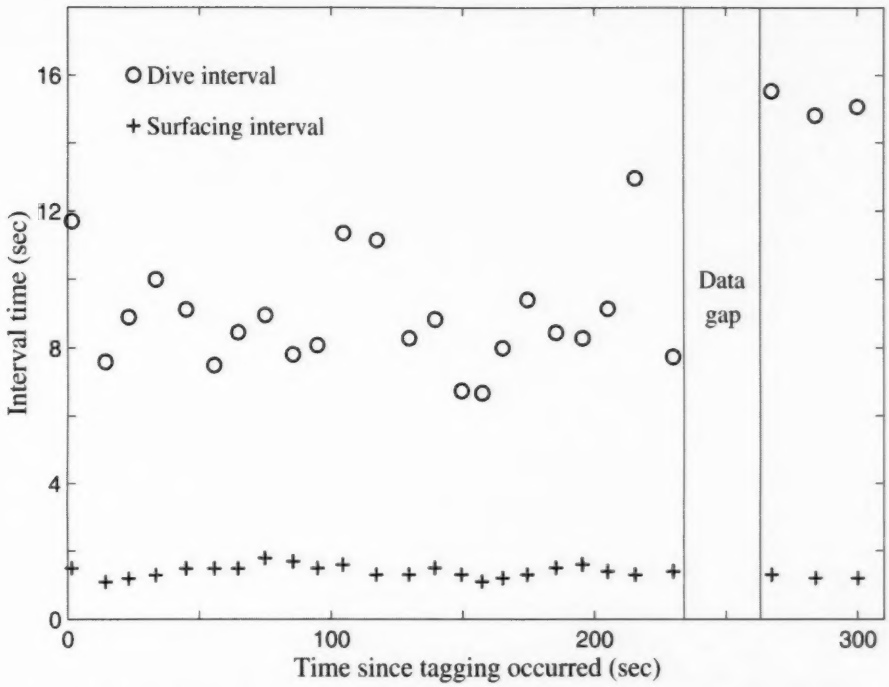


Figure 6.—Surfacing behavior of a beluga tagged on 11 June 1994 in Cook Inlet, Alaska. Data were obtained from videotape observations taken immediately after tag deployment. The break in the data at about 230 sec is due to a gap in the video record (although the surfacing was captured on the audio recording, precise timing could not be determined).

for the two types of surfacing behavior. Because the duration of a tagging bout averaged only 2.7 min, usually only 1–3 surfacings occurred before the bout was terminated.

Whale DL11-94 exhibited only head-lift behavior from the time it was tagged to the termination of video tracking (5.25 min). The mean dive interval was 10.3 sec (SD=2.5 sec, n=26). This was significantly less than the mean dive intervals of the five whales tagged for >60 min. The mean surfacing interval was 1.34 sec (SD=0.31 sec, n=28). Toward the end of the tracking period, the dive intervals appeared to increase and become more variable, while the surfacing intervals did not (Fig. 6).

Discussion

Based on our study, belugas appeared to recover quickly from disturbance. The whales displayed a strong fidelity for the study area and often approached the tagging vessel after the conclusion of a tagging bout. Head-lifting behavior appeared to be correlated with disturbance. Under similar environmental conditions, the fraction of surfacings that were head-lifts was considerably higher for pursued whales than for undisturbed whales. Tagged belugas did not display strong reactions to the tags (i.e. their reactions did not appear to differ from whales that were not pursued or tagged but fled during vessel operations). Unlike the bottlenose dolphins studied by Schneider et al. (1998), the tagged belugas made no apparent vigorous behaviors to remove the tags.

The mean dive intervals estimated in this study do not differ significantly from those estimated for the two whales tagged by Frost et al. (1985; 31 sec and 26 sec). Natural variability in the dive behavior of individual whales in a population is not unusual and probably accounts for much of the variability observed in the five belugas we tagged. These whales had a considerable range in size and age (Table 1). Seasonal variations in behavior may also account for some of the variability. Tagging operations in 1994 occurred in June, whereas operations in 1995 occurred in August.

Several factors related to tagging that may introduce biases in the observed surfacing behavior are listed below. Assessing their importance is difficult and beyond the scope of this paper. First, there was no apparent trend in dive behavior with time after tagging (Table 3). However, this does not definitively indicate that the tagged whales behaved "normally" and had recovered from the stress associated with the tagging pursuit before or during the period when data was being collected. Second, reactions to the presence of the tag that are not easily observed in the field may also bias the estimated surfacing behavior. Third, it is possible that, on occasion,

only a faint signal or no signal at all was received when tagged whales surfaced.

When the whales tagged in 1995 were observed during photographic operations, nearly all surfacings (both headlifts and slow-rolls) observed visually were detected by the radio-tag monitor. These tags were located near the dorsal ridge of the whales (Table 1), a location that was very likely to come near the surface (especially during slow-rolls). The tag on DL4-94, however, was attached on the tail stock, an area less likely to come close to the surface. We believe nearly all slow-roll and headlift surfacings were detected using the radio tags when tags were placed near the dorsal ridge, but a careful study is necessary to confirm what fraction of surfacings were missed.

Even though transmitters provide a useful relative measure of the length of surfacing intervals, the duration of a transmitter's signal does not necessarily give the total time a whale is visible above the water. The whale's rostrum is probably exposed before the transmitter antenna breaks the surface, and the lower back and tail stock probably remain exposed after the antenna has resubmerged. This is confirmed by mean surfacing intervals from aerial (Hobbs et al., 2000b; $\bar{x}$=2.59 sec, SD=0.67 sec, n=155) and vessel video records (Fig. 5c), which were both higher than the mean time at the surface obtained from the radio-tag data. In this case, measurement of the time a surfacing whale is visible in video records is a much more direct and effective method than using radio-tag signals.

An unbiased sample of dive intervals for belugas in Cook Inlet is extremely difficult to obtain without the use of remotely sensed tags. Visual tracking of individual whales in a group is not possible because of the highly turbid water of the inlet, the irregular swimming patterns of the whales, the lack of obvious markings, and the large group sizes. Only short, continuous visual records of surfacings can be obtained before whales are either lost or confused with other whales. Such records are biased towards short dive times because whales are more likely to be lost during longer dives. With radio tags, long, continuous and unbiased dive records can be obtained.

The longest amount of time one of our tags remained on a whale was >6.9 h. Longer deployments are desirable in order to reduce the effect of stress associated with tagging the whale, and allow for studies of the temporal variability (e.g. at tidal and longer time scales) of diving behavior and of whale movements. An option for obtaining longer time series is to attach satellite packs onto the whales.

Capturing belugas and pinning instrument packs to their dorsal ridges has occurred successfully elsewhere (Frost et al., 1985; Martin and Smith, 1992; Heide-Jørgensen et al., 1998). On the Susitna River delta, attempts to capture and hold belugas for attaching satellite tags were unsuccessful in the 1995 and 1997 field seasons. However, satellite tags were successfully attached to one whale in 1999 and two whales in 2000. In addition, a suction-cup tag with a time-depth recorder (TDR) was attached to one of the whales in 2000 and remained on the whale for approximately 90 h. Satellite packs pinned through the dorsal ridge have remained attached to belugas for >3 months, and provide much more information about long-term whale movements and dive patterns than the radio transmitters used on our suction-cup tags.

This study is the first attempt to characterize the surfacing behavior of belugas in Cook Inlet. The sample size must be increased to better understand the range of behavior between individual whales and within different environmental conditions in the inlet. We believe that, with minor modifications to our attachment system, tag deployments as long as several days can be obtained (as has been shown with the suction-cup attached TDR deployed in 2000). Radio transmitters do not collect the detailed dive and whale movement information possible with satellite transmitters and TDR's. However, the cost of the tags used in our study is only one-tenth the typical cost of satellite tags. We believe that the methods employed in this study are a low-cost alternative for obtaining surfacing behavior data from a large sample of whales, which is required to estimate correction factors for the abundance of Cook Inlet belugas.

Acknowledgments

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Development of Beluga, *Delphinapterus leucas*, Capture and Satellite Tagging Protocol in Cook Inlet, Alaska

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Introduction

Belugas, *Delphinapterus leucas*, are widely distributed across Arctic and subarctic waters of the northern hemisphere (Gurevich, 1980), with five stocks recognized in coastal areas of Alaska (Frost and Lowry, 1990; O'Corry-Crowe et al., 1997). Among the Alaska stocks, only the belugas in Cook Inlet are endemic to the Gulf of Alaska; all others occur north of the Alaska Peninsula (Frost and Lowry, 1990). The Cook Inlet stock is the least abundant, with a population estimate as low as 347 animals in 1998, down from 653 in 1994 (Hobbs et al., 2000a).

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ABSTRACT—Attempts to capture and place satellite tags on belugas, Delphinapterus leucas, *in Cook Inlet, Alaska were conducted during late spring and summer of 1995, 1997, and 1999. In 1995, capture attempts using a hoop net proved impractical in Cook Inlet. In 1997, capture efforts focused on driving belugas into nets. Although this method had been successful in the Canadian High Arctic, it failed in Cook Inlet due to the ability of the whales to detect and avoid nets in shallow and very turbid water. In 1999, belugas were successfully captured using a gillnet encirclement technique. A satellite tag was attached to a juvenile male, which subsequently provided the first documentation of this species' movements within Cook Inlet during the summer months (31 May–17 September).*

Belugas in Cook Inlet are considered an important resource for Native Alaskans, and they are harvested by members of local tribes and emigrants from Native communities in western Alaska (Huntington, 2000; Shelden and Mahoney, 2000). However, the combination of low abundance and recent trends in exploitation has raised concerns for the viability of belugas in Cook Inlet. Consequently, determination of population status and trends in abundance has become a high priority mission for NOAA's National Marine Fisheries Service (Hill and DeMaster, 1998).

Monitoring the status of the Cook Inlet belugas requires an estimation of the number of animals in the population. Estimation of population number requires: 1) the conduct of annual aerial surveys (Rugh et al., 2000) and 2) calculation of correction factors to account for animals below the surface at the time of survey (Hobbs et al., 2000b). Calculation of correction factors requires a means of determining the dive profile of belugas during typical survey conditions.

Since 1994, the NMFS has fielded four tagging efforts to deploy instrumentation on belugas to collect dive profile data. These projects involved either pursuit and subsequent application of short-duration telemetry transmitters (Lerczak et al., 2000) or attempts to capture and attach long-term satellite-linked time/depth recorders, the subject of this paper.

Beluga capture and tagging has been successfully accomplished many times in the Canadian High Arctic (Martin and Smith, 1992), and recently along the northwestern coast of Alaska (Suydam et al., 2000). This paper chronicles three field seasons of beluga capture in Cook Inlet since 1995, with emphasis on the 1997 and 1999 seasons. In particular, the development of the capture strategy and the constraints imposed by the challenging environmental conditions in upper Cook Inlet are described.

Methods and Materials

Study Area and Conditions

The study area at the mouth of the Susitna River is about 35 km west of Anchorage (Fig. 1). Extreme tides, high winds, and extensive shallows characterize this area of upper Cook Inlet (Moore et al., 2000) and often compromise beluga capture attempts. For example, tidal range at Anchorage is roughly 9.5 m (30 ft). Thus, at low tide, the exposed flats at the mouth of the Susitna River extend as much as 6 km, while at high tide, those flats and much of the coastal lowlands may be under water. Typically, the incoming tide will rise at a brisk rate of about 2 m/h.

Strong winds, particularly easterlies out of Turnagain Arm, often occur in the afternoon as cooling air descends the Chugach Mountain slopes and surges across the inlet. Such turbulence often degrades survey conditions, making beluga sightings or tracking impossible, even at close range. Often, the combination of winds driven over shallows and the rapid pace of the tidal exchange create confused seas that are marginal or unsuitable for small boats. Under these conditions, transit to or from Anchorage is extremely hazardous and capture work is impossible.

Thus, typical of many large river deltas in such an extreme environment, the water in the study area is both dan-

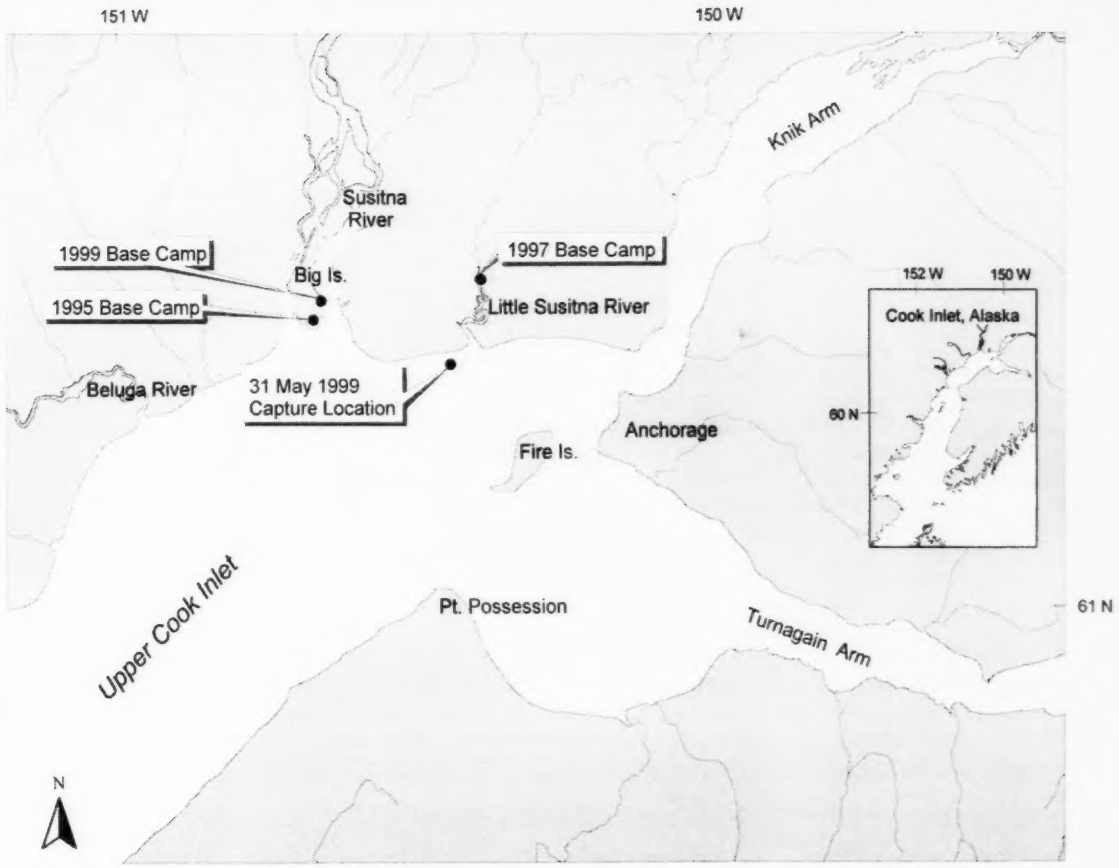

Figure 1.—Upper Cook Inlet, showing locations of base camps in 1995, 1997, and 1999 and location of beluga capture in 1999.

gerous and highly turbid, often with visibility < 20 cm (Moore et al., 2000). Such conditions limit direct observation of belugas to 3-sec intervals when they surface (Hobbs et al., 2000b), which makes visual tracking difficult. Rugh et al. (2000) describe problems that turbidity presents for interpretation of aerial survey counts; similar difficulties plague location and monitoring of belugas while on the water. In addition, belugas in Cook Inlet are not easily approached, possibly a result of many years of human pursuit for harvest. When disturbed, the belugas often move toward deep water and resist herding to shallower, more suitable capture locations. If belugas can be herded to shallow water (i.e. <2 m), a "bow" wave is generated by their movement through the water which provides a reference to their location underwater.

In summary, these factors dictate a narrow set of field conditions within which beluga capture techniques have been developed in Cook Inlet. Specifically, whales must be found and herded to shallow water when winds are light and seas are relatively calm (7–10 kn; Beaufort sea state ≤3) and the tide is near its high level (± 2 h). Of note, belugas are more likely to swim into shallow areas on extreme high tides (i.e. above +8 m). Means to maximize field time under these conditions have developed over the years, as have the capture techniques.

Boats and Tags

A variety of small boats were used as platforms for tagging over the years. Generally, such craft consisted of one or more inflatables, ranging in size from 3.5 to 6 m, and open aluminum or wooden skiffs up to 8 m. For net deployment, Boston Whalers (6–7 m) were outfitted with net bins aft of the center console and stanchions across the stern to allow the net to travel over the outboard motor. From four to six boats were used at any given time during the capture and search efforts. The four boats used during the successful capture in 1999 included a 6.5 m aluminum Boston Whaler carrying the capture net, a 5.5 m Avon inflatable, a 5 m Zodiak inflatable, and a 7 m aluminum Munson.

Capture nets used in 1997 and 1999 were constructed of 0.3 m braided square mesh gillnet, sewn in panels 125 m long × 4 m deep. The float line was

made of 3.5 cm diameter polypropylene; 2 cm lead-core line ran the full length of the foot. The VHF radio tags are described in Lerczak et al. (2000). Model SDR-T-16 satellite-linked tags (SLT) were purchased from Wildlife Computers, based in Redmond, Wash., with programmable transmission periods to maximize battery life. Details of SLT performance and specifications are available on Wildlife Computers web page [www.wildlifecomputers.com].

Results

Field Studies in 1995

Building on lessons learned during the 1994 field season, when VHF transmitters were first attached to Cook Inlet belugas (Lerczak et al., 2000), attempts were made from 18 to 31 July 1995 to capture and equip belugas with satellite-linked time/depth recorders (SLTDR's). The SLTDR's are capable of recording location and dive data for 3 mo or more. The tag packages also contained a built-in VHF transmitter, identical to those on the suction-cup tags used in 1994 (Lerczak et al., 2000) to allow real-time local monitoring of whale movements.

The wide deltas at the mouths of the Susitna and Little Susitna Rivers were chosen as the study area based on consistent presence of belugas in that area during late spring and early summer (Rugh et al., 2000). The field camp was based on the east side of Big Island near the mouth of the Susitna River. The field crew included two Native Alaska beluga hunters to help locate and track the whales, a beluga researcher who had tagged whales in the Canadian Arctic, and NMFS personnel. The proposed capture method, developed during the Canadian studies (Smith and Martin, 1994; Smith[1]), involved one person outfitted in a dry suit jumping from a small boat (6 m/75 hp) next to a surfacing beluga and sliding a hoop net (2 m diameter, 8 cm web sewn to form a 2.5 m cod end) over the animal's head. A second person would then jump in to fasten a 2.5 cm soft nylon line around the caudal peduncle to further restrain the animal.

Conditions in upper Cook Inlet were completely different from those encountered in northern Canada. The Canadian study area was characterized by clear waters (with little or no tidal influence) adjacent to beaches offering ready access to belugas. Monitoring the location of animals during pursuit, and determination of water depths sufficiently shallow for the "jumper" to stand on the bottom were greatly facilitated by clear water (Smith and Martin, 1994). Turbid waters in the Susitna delta impeded adequate tracking of whales to get in position for a jump. Likewise, because the water depth could not be judged with certainty, neither the safety nor the effectiveness of a jump could be assured, even if a beluga were in the proper position for capture.

Only two jumps were made, neither of which were successful in placing the hoop net. Thus, after >30 h of effort, the combination of water turbidity and evasive whale behaviors thwarted all attempts to use the jump-capture method, and the technique was abandoned. After terminating these capture attempts, the field team resumed working on a day-trip basis out of Anchorage to place suction-cup tags on whales (Lerczak et al., 2000).

Field Studies in 1997

In 1997, the beluga tagging effort focused entirely on attempts to capture one or more whales for SLTDR attachment. To increase opportunities to locate and work with whales, the field plan included a longer season, larger crew (including two Native Alaska beluga hunters), and a more fully equipped field camp. A new capture method was devised based on the recommendations of the Canadian beluga researcher present during the 1995 study (Smith[1]).

The new capture method involved driving target animals into a large-mesh gillnet (Fig. 2), and required four boats. The net was designed for deployment from a bin at the stern of the capture boat (a 6.5 m Boston whaler), over a 1.5 m high stanchion made of 6 cm aluminum pipe clamped to the stern. This arrangement allowed the net to be stored fully inside the boat, keeping its center of gravity low, while providing a means for the net to pay out smoothly astern, over the top of the outboard motor.

Unlike fishing, where a gillnet is set in a suitable location and allowed to passively intercept the target species, the beluga capture net needed to be actively set in real-time and immediately in front of the target animal. This approach required close coordination among at least four boats: 1) a lead boat to single out and track the target animal, 2) a capture boat equipped to deploy the net, and 3) two or more chase boats to drive the target animal towards the net.

As planned, the lead boat was to keep pace with the target animal, herding it in a predictable direction across the submerged flats shallow enough for the net to hit bottom. The capture boat, meanwhile, was positioned for deployment slightly astern and to port of the leader. On a signal from the lead boat, the capture boat accelerated rapidly, and a drag buoy attached to one end of the gillnet was tossed over, laying the net across the animal's path. The lead and chase boats then moved in behind the animal, attempting to drive it into the net. The final step of the capture plan, assuming a successful entanglement, entailed one or more boats moving alongside the animal to stabilize it at the surface. Tag attachment would then proceed in nearby shallower and calmer water.

The project was designed to take advantage of every high tide when weather conditions were suitable for capture work (i.e. high tide ± 2 hours and Beaufort sea state < 3). Because extreme high tides were expected to flood most of the land around the Susitna River mouth during the field period, a new site 7.5 km up the Little Susitna River was chosen for the project base.

Despite nearly 3 wk of effort, no belugas could be driven into the capture net long enough to become entangled. On 14 occasions, the net was set ahead of individual belugas, and each time the animals simply reversed direction, evaded the small boats then stayed well away from the immediate capture-attempt area. Because of the field camp's location, a great deal of crew time and energy was spent monitoring and rescu-

[1] Smith, T. G., Eco Marine Corporation, Ladysmith, B.C., Can. Personal commun.

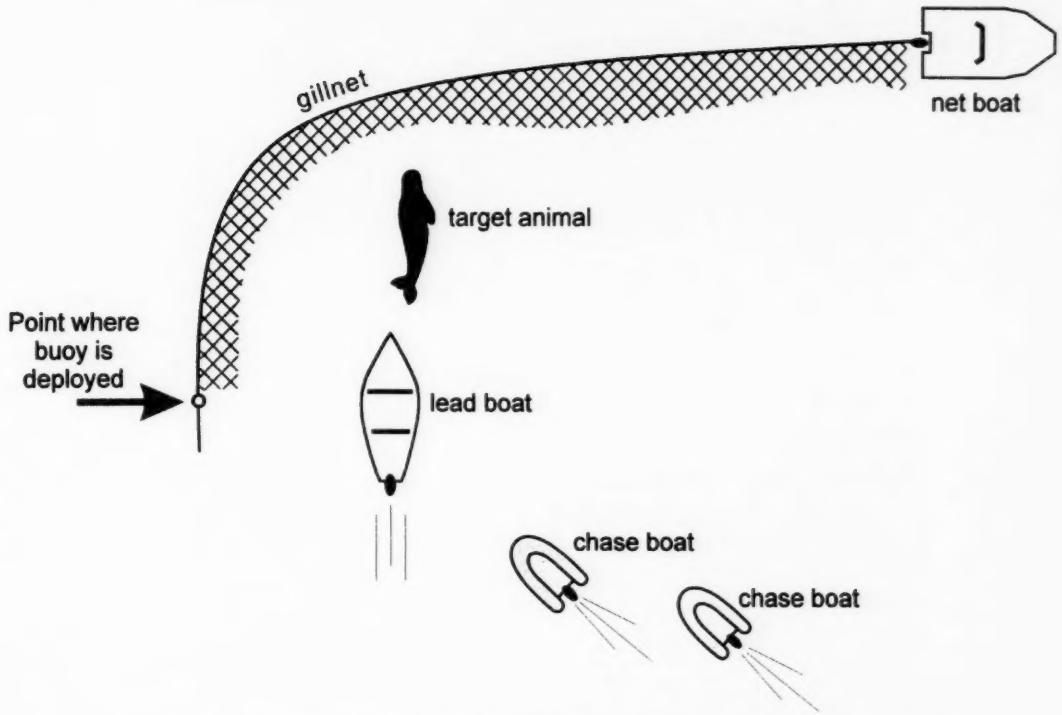

Figure 2.—Schematic drawing of a beluga capture using a "drive approach," as attempted in June 1997.

ing boats and equipment. Finally, wind conditions in upper Cook Inlet and mechanical breakdowns further impacted capture efforts. Over 21 days of field work, winds or logistical problems hampered efforts during one or both tidal windows every day.

In addition to logistical problems, the belugas seemed to change their behavior and distribution during the course of the 1997 field season. After the first week (3–10 June), they became more dispersed, and when located they were more wary of approaching vessels. Two factors may have influenced their behavior: 1) the timing of the Pacific salmon, *Oncorhynchus* spp., and forage fish spawning runs and 2) increased frequency of Native subsistence hunting in the area. Spawning runs peaked in late May, roughly a week before our arrival. At the beginning of the field season, belugas were seen in the rivers or very close to the river mouths, presumably feeding on the fish runs. As the runs diminished, the belugas appeared to be less aggregated at the river mouths. Concurrently, however, the intensity of subsistence hunting activity increased, particularly in the mouth of the Susitna River. During this time, most animals became very difficult to approach, fleeing almost immediately to deep water (see Appendix).

Although no belugas were captured in 1997, three key observations were made which ultimately provided a foundation for success in 1999. First, more whales could be encountered close to the mouths of the Susitna and Little Susitna Rivers in shallow water if the field work occurred earlier, during the peaks of the chinook salmon, *O. tshawytscha*, and eulachon, *Thaleichthys pacificus*, runs. Second, entanglement in large-mesh gillnets could work, but only if the target animal was fully encircled and had no opportunity to double back to open water. Third, to accomplish full encirclement, we found that a longer net was needed with capability for deployment at high speeds (≥ 25kn).

Field Studies in 1999

Beluga capture and satellite tagging in upper Cook Inlet was conducted from 24 May through 3 June, with the aforementioned lessons from 1997 incorporated into a revised capture strategy. Thus, the field season began earlier, the capture gear and methods were modified, and the field camp was relocated to the 1995 site.

When winds did not preclude boat use, a crew of seven biologists and two Native hunters searched for belugas during each high tide during daylight hours. The shallow channels of the Susitna River adjacent to the field camp were generally navigable from about 2 h before to 2 h after high slack tide, which defined the typical "capture effort" window.

Once whales were located, usually between the Susitna River delta and the mouth of the Little Susitna River, the

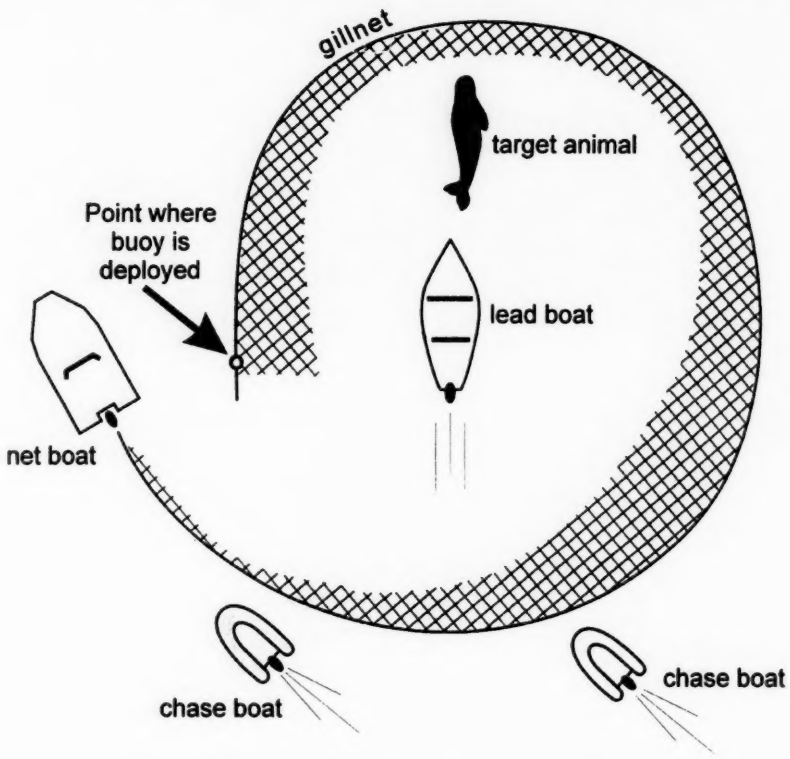

Figure 3.—Schematic drawing of a beluga capture using the "encirclement approach," as successfully accomplished in June 1999.

hunters isolated an individual animal and drove it into water about 2 m deep. When a target animal was moving consistently ahead of the hunter's boat, the catch boat was brought into position on the port stern of the hunters' boat. The drag buoy (a 0.5 m diameter mooring float), attached to about 175 m of net (same depth and mesh size as in 1997) was then deployed. Immediately, the catch boat accelerated to about 25 kn, overtook the target animal and executed a tight clockwise turn back to the point of initial deployment (Fig. 3) to set the net completely around both the beluga and the boat.

This approach eliminated the need to subsequently drive the beluga into the net, as its escape by doubling back was fully blocked by net. As the animal attempted escape, it would eventually contact the gillnet, pushing the mesh and floatline into a "V" shaped channel that progressively closed in around it. Once entangled, the animal was tended to by personnel in the nearby boats. Ultimately, the hoop net was slipped over the animal's head, and a tail loop was placed around it's caudal peduncle. Tag attachment began after moving to waist-deep water where the crew members could work alongside the animal.

Unlike the 1997 effort, camp placement and more favorable weather conditions allowed the crew to maximize the number of possible capture attempts and to avoid the dangers associated with operating in the upper reaches of the Little Susitna River channel. Of 18 possible high tides occurring in daylight, 12 were worked and 6 were not worked due to winds or logistical considerations. Twelve encounters with groups of 50–100 whales occurred during the 12 high-tide cycles. Each of these encounters was followed by capture attempts on individuals in a portion of the total group (see Appendix).

The highlight of the 1999 field season was the successful deployment of a SLTDR on a young male beluga. On the morning of 31 May, weather conditions were favorable and a group of about 100 belugas were located 2 km up the Little Susitna River. A variation of the net deployment system was devised in an attempt to capitalize on the location of so many whales in the relatively narrow river channel. One end of the net was anchored to the beach on the inside of the last bend of the river and deployed upstream along a shallow bar, thus forming a beach seine into which animals might be driven. At least 5 whales approached the seine, with the young female actually entering it and becoming entangled. Too small to tag (at 230 cm), she was quickly measured and released within 10 min of capture.

Soon after, the same group of whales was rediscovered well into the shallows, west of the Little Susitna River, a perfect location for capture. After one unsuccessful try, the crew targeted several whales in the shallows. This time, a full encirclement was achieved, capturing two animals, although one eventually broke free. Once the remaining whale (a grayish-white, 370 cm, male) was stabilized with tail loop and hoop net in place, it continued efforts to swim until the tide dropped enough for it to rest on the bottom. Other than calling during the capture, tagging, and subsequent stranding, the whale showed little response to the tag attachment (Fig. 4). After receiving a continuous water bath over the low tide cycle (about 6 h), the animal responded to the first touch of incoming water, oriented itself toward deep water and began moving, even before fully refloating (Fig. 5), and 10 min later, the whale rejoined a group milling nearby (see Appendix for further details of SLTDR attachment).

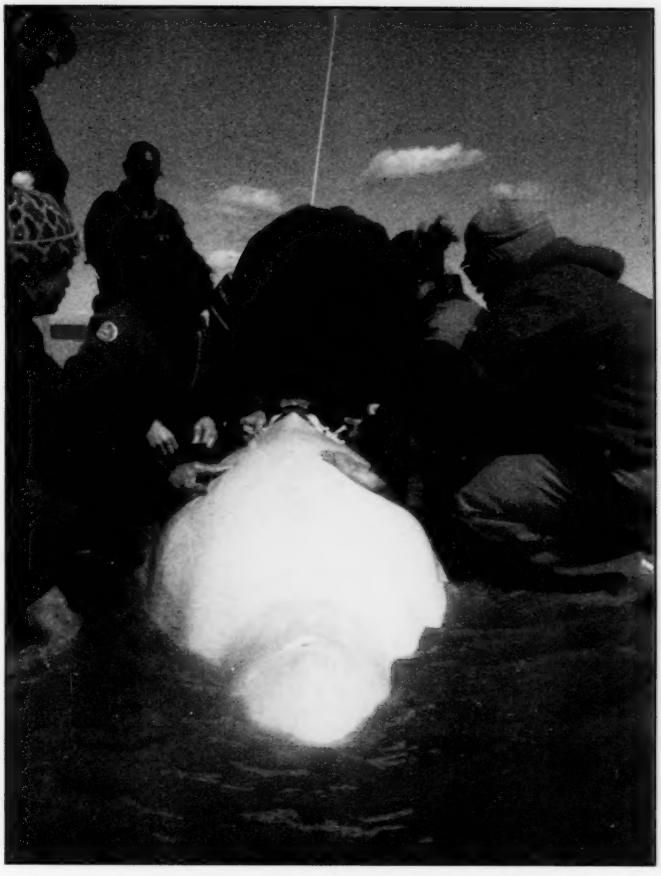

Figure 4.—Members of the tagging team attaching a SLTDR package to a juvenile male beluga in upper Cook Inlet on 31 May 1999.

Movement Patterns

Preliminary results from SLTDR data for this animal suggest that belugas remain in the upper inlet over much of the summer (Fig. 6). The SLTDR transmitted for a total of 110 days, providing locations and dive pattern data from 31 May to 17 September, during which time the whale never traveled more than 60 n.mi. from the original point of capture.

Five distinct movement patterns were observed. From 31 May to 13 June, the whale was located near the mouth of the Little Susitna River, consistent with the pattern we observed during the capture (Fig. 6a). From 14 June to 11 July, the whale's movements were more broadly distributed in an area bounded on the west by the Beluga River, Point Possession to the south, and Fire Island to the east (Fig. 6b). Beginning on 12 July, the beluga moved back into the area of the Little Susitna River, perhaps coincident with the progression of the Little Susitna drainage coho salmon run (Fig. 6c). After 18 August, nearly all locations recorded through 12 September were in Knik Arm, particularly in the area adjacent to the mouth of the Eagle River (Fig. 6d).

Occasional trips back to the Little Susitna River area were also observed. On 13 September, the animal left Knik Arm and entered Turnagain Arm where it remained for 5 days after which the signal was lost (Fig. 6e). Dives were predominantly short (1–2 min) and shallow (<2 m) with the exception of an occasional deeper dive (about 55 m) in lower Knik Arm, west of Anchorage.

Discussion

As might be expected with any new field study, the development of successful capture and tagging techniques ultimately involved a good deal of trial and error. In upper Cook Inlet, three seasons of learning were required before a SLTDR was successfully attached in 1999. Collectively, these experiences provide a foundation for refinements to the capture technique, particularly with regard to net construction and deployment. In particular, we hope to improve the stanchion system, modifying it to allow a smoother path for the net over the aft starboard corner of the boat.

A total of 110 days of data were received from the SLTDR before the signal was lost in early September. During that time, the tagged whale never left the upper inlet, a result consistent with recent reports on summer distribution of Cook Inlet belugas (Rugh et al., 2000). While these data report the movements of only a single animal, it is noteworthy that this whale seemingly spent the entire summer in the upper

inlet. In the future, project goals will include deployment of SLTDR's on multiple animals to cover a broad range of ages and sexes. Distribution and movement data from all seasons are also desirable. Given the limited satellite tag life expectancy (up to about 4 mo), information from the fall and winter are unlikely to result from tagging in May or June. Consequently, an expansion of the tagging project to include capture efforts in late summer or fall may also be considered.

Finally, surfacing interval data collected in real-time from the VHF transmitter will be compared with the data collected by the SLTDR package in an effort to refine estimates of surface time and thereby improve estimation of whales missed during aerial surveys. Data from a number of tagged whales is required to improve our understanding of beluga dive profiles and thereby inform our estimates of whales missed due to submergence. Hopefully, additional years of tagging effort will provide those data.

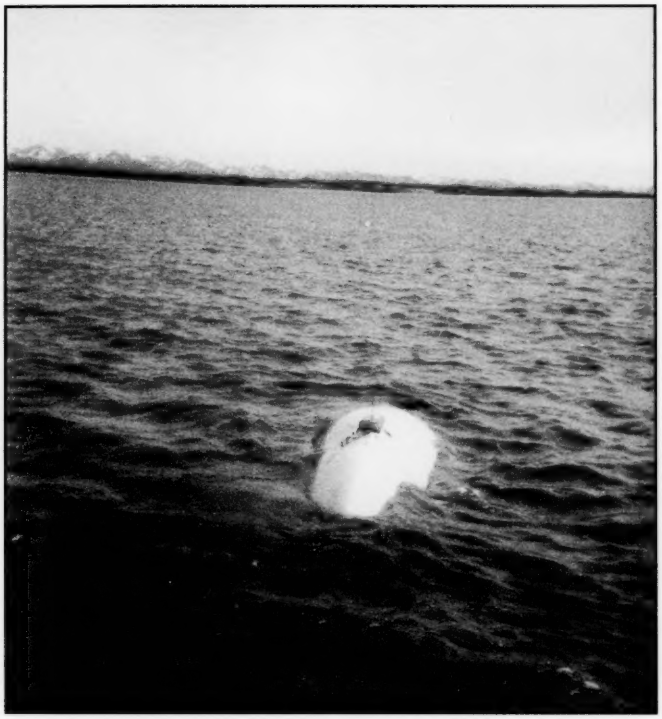

Figure 5.—Beluga with the SLTDR package attached to its dorsal hump swimming away on 31 May 1999.

Acknowledgments

The participants in these three field projects are to be commended for their teamwork and persistence: Artur Andriolo, Jack Cesarone, Doug DeMaster, Korke and Rusty Dimmick, Matt Eagleton, Clyde Eben, Brad Hanson, Scott Hill, Marc Lamoreaux, Jim Lerczak, Laura Litzky, Barbara Mahoney, Paul Nader, Art Nuglene, Greg O'Corry-Crowe, Denty Owens, Dave Rugh, Dana Seagars, Mike Secuse, Kim Shelden, Tom Smith, Steve Thumm, Ricky Tocktoo, Dan Vos, Janice Waite, and Bill Walker. Kim Shelden's editorial assistance was especially appreciated. Likewise, we thank Gary Duker, and James Lee for technical editing.

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Appendix: Chronicle of Attempts to Capture Belugas in Cook Inlet, Alaska, During 1997 and 1999

1997 Field Season

11 JUNE: A group of roughly 50 belugas were loosely aggregated over a 1–2 mi^2 area of the Susitna River delta. Individual belugas were isolated and coaxed

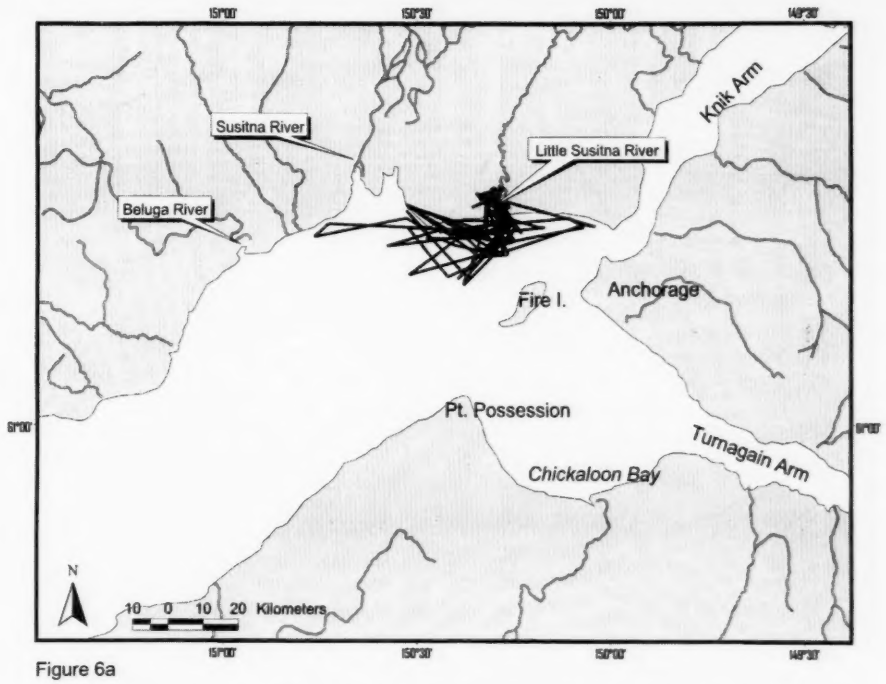

Figure 6a

Figure 6.—Preliminary results depicting locations of the tagged beluga, 31 May to 17 Sept. 1999 (straight lines link SLTDR derived positions and do not indicate actual movement patterns). Successive whale positions are summarized for five periods: a) 31 May through 13 June; b) 14 June through 11 July; c) 12 July through 15 Aug.; d) 18 Aug. through 12 Sept.; and e)13–17 Sept.

four times into capture positions in shallow water. Capture attempts were limited to two tries per animal, and thus two separate whales were targeted. On each try, 50 m of net was set ahead of the animal. Three times the animals doubled back from the net and swam around the small boats attempting to drive it into the net; the whales avoided the area of the net despite efforts to move them back toward it. However, on the first set, the animal did hit the net and was briefly entangled. After about 10 sec, it broke free and doubled back under the chase boats. The animals appeared quite capable of detecting the net and moving rapidly into channels offering deeper water.

12 JUNE: A group of about 50 belugas were found near the mouth of the Susitna River. Four capture attempts were made using 100 m of net which allowed formation of a semicircular barrier. Two animals were targeted two times each for a total of four sets. Once again, one animal hit the net, but appeared to graze it rather than becoming entangled. The other three avoided the net by circling around the ends of the net. On all four occasions, the whales moved into deeper water and evaded further efforts to move them into suitable capture position.

13 JUNE: A group of about 100 animals were briefly seen from a distance of about 4 km in Knik Arm, but attempts to approach them were unsuccessful. No animals were targeted, nor were any sets made.

17 JUNE: A scattered group of about 35 whales were located on the west side of the mouth of the Susitna River. One animal was isolated, moved to shallow water, and a set was made with 100 m of net, the middle 35 m of which had been modified to a mesh size of about 0.6 m in hopes of increasing the probability of entanglement with minimal contact. As in earlier attempts, however, the whale turned before hitting the net, reversed direction and swam around the net end. Subsequent attempts to move the animal into capture position were unsuccessful. A second animal was located and two attempts at capture failed. The capture position was adjacent to a deepwater channel which provided an escape route after initial avoidance of the net.

18 JUNE: Small, scattered groups of belugas (4 groups of 5–10 animals each) were seen well outside the Susitna River mouth. None of the animals could be herded to shallow water so no sets were made.

19 JUNE: Rough seas and poor visibility near river mouths curtailed capture efforts in the river deltas; however, a group of about 20 belugas were located 3.0 km up the Little Susitna River and two capture attempts were made.

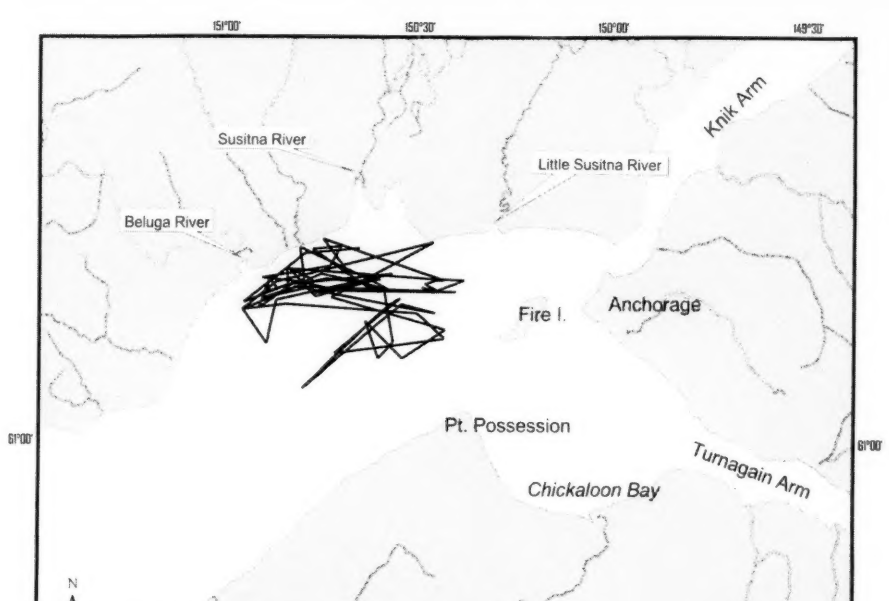

Figure 6b

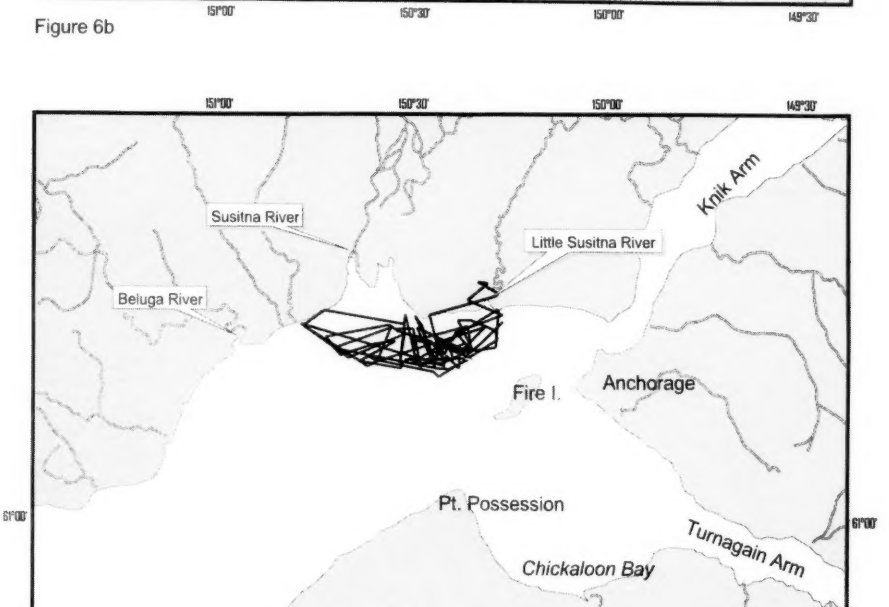

Figure 6c

Figure 6.—*Continued.*

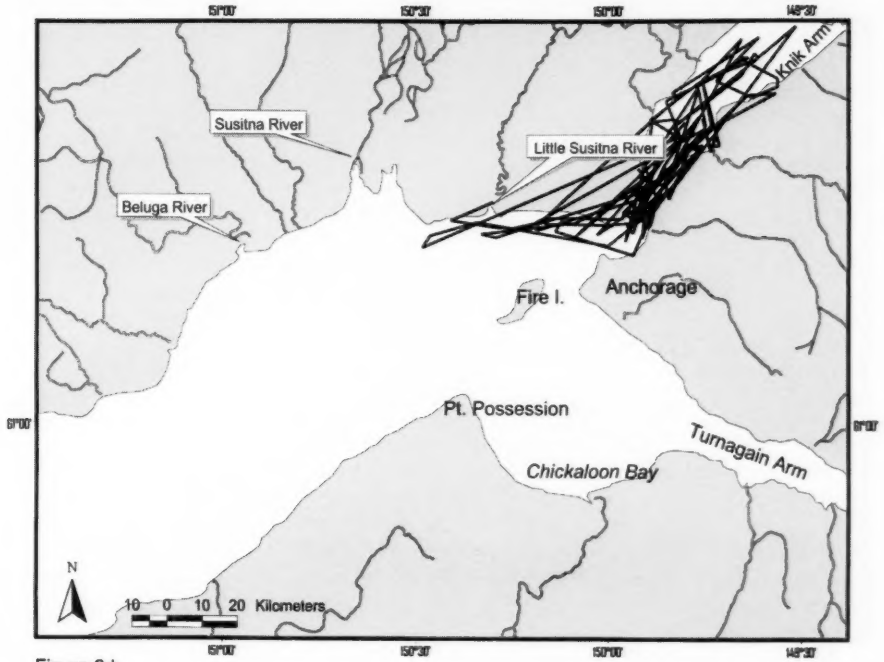

Figure 6d

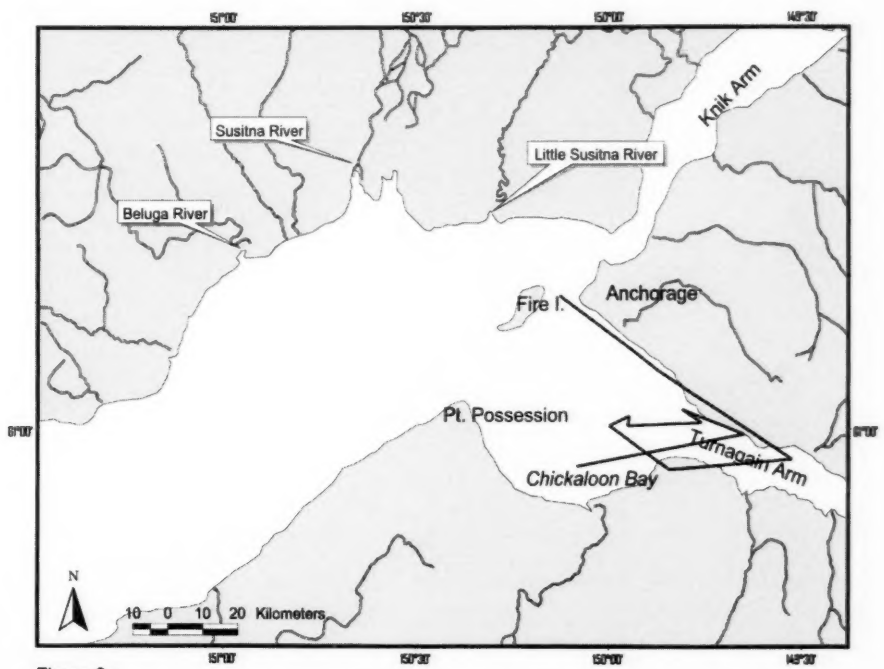

Figure 6e

Figure 6.—*Continued.*

The channel depth was over 8 m, well beyond the reach of our nets, so we set the nets rapidly in front of the animals in hopes of entangling them before they changed direction. But each time a targeted animal approached the net, it dove, subsequently resurfacing downstream. The belugas were clearly able to respond rapidly, avoid the net, and dive beneath it.

20 JUNE: The capture team worked both of the high-tide periods across the entire length of the study area. Belugas were sighted in deep water each time, but well away from the river deltas. Those individuals were in widely scattered small groups, and essentially unapproachable, diving before we could close within 1.0 km. No sets were attempted.

21 JUNE: On the morning tide, a small group of belugas was located in the mouth of the Susitna River. One individual was moved into the shallows in a suitable capture location, and a set was made. The animal struck the net twice, each time very briefly, perhaps with its flukes as it turned away from the net. Attempts to move the animal back toward the net were unsuccessful, and it eventually reached a deepwater channel and swam away from the river.

22 JUNE: A group of 6 belugas were sighted in the Susitna River delta and approached. All six animals were gray, indicating that they were young and not suitable as capture targets. No sets were made, and no other belugas were found in the area.

1999 Field Season

25 MAY: Weather during the morning high tide was too windy to attempt small boat travel. By the afternoon, the winds had subsided and the crew departed camp at about 1430 h. A group of about 100 belugas were found 2 km up the Little Susitna River. Moving slowly downstream, the boats were used to drive the animals out of the river to the adjacent shallows where attempts were made to isolate an individual in shallow water. After nearly an hour of unsuccessful attempts to position an animal, the decision was made to begin the trip back to camp, although the tide had already dropped too low to make reaching it certain. At about 2100 h, the Boston whaler went hard aground on a sand bar while the other two shallower draft boats reached the shoreline on the west channel of the Susitna River, but still stranded 5 km from camp. The team finally reached camp at about 0500 h the following morning. The late return trip on the ebbing tide the previous night eliminated the crew's ability to work the morning high tide due to fatigue and limited time available to refuel the boats.

26 MAY: The crew remained in camp and prepared the boats for the afternoon high tide. By 1500 h, however, the winds had risen too high to work. Instead, a watch was established on an adjacent island (Delta) in case belugas moved into the main channel of the Susitna River. No belugas were sighted.

27 MAY: Winds continued in the morning with marginal sighting conditions. A group of about 50 whales were encountered, but could not be moved to a suitable capture location. No sets were made. Likewise, during the afternoon high tide, conditions were marginal and no whales were found.

28 MAY: Weather during the morning high tide was clear and calm; the team was on the water by 0500 h. No whales were seen between the Susitna River and the shoreline 3 km north of the Little Susitna River and the crew returned to camp several hours later. At about 1830 h, the team headed out on the evening high tide and met the two Native hunters joining the project. Together, the team traveled about 4 km toward the Little Susitna River before encountering a group of 50 whales well into the shallows. Attempts were made for about 0.5 h to position an animal for capture. Eventually, a large white adult was singled out of the group and a set was made. With about half of the net deployed, however, the webbing snagged on the corner of the stanchion, tearing it out of the stern mounts. The stanchion stayed in the stern of the boat, however, and the remaining net was paid out over the aft starboard side by hand.

Despite the mishap, the beluga remained in the net and was forming a "V" channel as it tried to escape to deeper water. The Zodiak crew reached the animal and maneuvered into position to affix a tail loop. The team members had hands on the animal's flukes and caudal peduncle and were just seconds from slipping the tail loop on, when the beluga broke free; the net had slipped over its back. Instead of becoming well wrapped, the whale had been pushing against the taut webbing, which, was not wide enough to securely entangle its head.

29 MAY: The winds were blowing too hard in the morning to go out. In the afternoon, the winds moderated enough to search for belugas, but none were seen. Sighting conditions were marginal with steady rain.

30 MAY: Weather during the morning high tide was favorable, allowing departure by 0600 h. Whales were quickly spotted midway between the Susitna and Little Susitna Rivers, well into the shallows. From the group of about 75 belugas, three individuals were singled out for capture in three separate capture attempts. In each case, major difficulties were again encountered with the net deployment system. In the tight, high-speed turns, the net was snagging on the starboard corner of the net stanchion, which resulted in tearing and incomplete deployment. Although whales were in good position for capture each time, only a portion of the net was out prior to the stanchion collapses, and complete encirclement was not achieved. Upon return to camp, four modifications were made to the deployment gear, including: 1) restacking of the net with the lead line on the starboard side of the net box so that it would be on the extreme inside of the turn, 2) the net box was tipped 15° aft to facilitate its travel up to the stanchion, 3) the stanchion itself was lowered about 0.6 m to reduce the vertical distance required for the net to travel before exiting, and 4) the starboard extension on the top of the stanchion was padded, and its width to starboard was extended by about 0.2 m using a deflated soccer

ball and duct tape to minimize snagging as the webbing rounded the stanchion corner. In addition, two badly torn net panels were replaced, and several tears were resewn.

In late afternoon, the boats and crew were once again ready to attempt captures. Belugas were found in about the same area as in the morning. A group of about 75 animals were targeted twice, and each time a single animal was maneuvered into capture position and a set was made. Given the difficulties with the net deployment earlier in the day, the evening sets were made more slowly to allow close monitoring of the gear. The modifications greatly reduced the net's tendency to snag, suggesting that future sets could once again be attempted at high speed. Given the moderated speed during the two evening sets, however, no animals were captured as they escaped prior to full encirclement.

31 MAY: Weather conditions were good for the morning high tide and the crew departed camp at 0530 h. A group of about 100 belugas were found 2 km up the Little Susitna River. Given the lack of success experienced earlier in the project when we attempted to move whales out of the river and onto adjacent shallows, a different net deployment was tried. One end of the net was anchored to the beach on the inside of the last bend of the river and deployed upstream along a shallow bar, thus forming a beach seine into which animals could be driven as they swam downstream. Most animals avoided the net, opting to swim closer to the opposite riverbank, but at least 5 whales approached the seine, with one eventually entering it and becoming entangled. The animal was a gray, subadult female, too small to tag (about 230 cm). The animal was measured and subsequently released less than 10 min after capture. Upon release it quickly rejoined the main group.

The team reformed and followed the same group of whales into the shallows west of the Little Susitna River. At 1030 h an unsuccessful set was made on a single white adult that escaped before a full encirclement could be achieved. The set was made at full speed with no deployment problems. At 1130 h a portion of the same group was again located in the shallows and the boats positioned for capture. A full encirclement was achieved, capturing two animals. One was well entangled, and tended by the hunter's boat. The second animal was forming a "V" channel when approached by the Zodiak. Adjacent to the animal, the Zodiak tangled in the net, requiring several minutes to be cut free. During that time, the nearby beluga broke free of the net and swam to deep water.

The first animal, still well entangled was then tail looped and its head slipped into a hoop net. The net panel entangling the animal was removed from the net and used to help secure the animal at the surface alongside the hunter's boat. The rest of the net was brought back aboard the Boston Whaler to be repaired and restacked later.

The beluga was slowly moved inshore alongside the hunter's boat until waist-deep water was reached. The animal, a white to grayish-white male measuring 370 cm was in good condition. It continued efforts to swim until the tide dropped enough for it to rest on the bottom, but otherwise showed little response to the tag attachment. Tag number 25850 (with a VHF transmitter 167.423) was attached to the dorsal ridge. Two 17″ identification bands, DL 00142 and DL 00141 were also fitted to the right and left flippers, respectively. The field number RCF 400 was assigned to the animal for entry onto a standard cetacean life history record.

Given the capture location (lat. 61° 13.81′ N, long. 150°17.26′W) well onto the tidal flats and the time required to complete the tag attachment, both the capture team and beluga were stranded through the low tide. During the stranding period, the animal was located in a shallow channel which was eventually dug out into a 0.4 m deep water-filled depression around the animal. Throughout the low tide, the animal was kept wet, and it's condition was monitored constantly. By 1830 h, the incoming tide had reached the animal. It began moving toward deeper water vigorously, even before fully refloating. Within 10 minutes the whale had reached the edge of the deep water and began a regular shallow diving pattern. It immediately rejoined a group of about 75 whales milling about adjacent to the edge of the tidal flats in deep water. The satellite tag was functioning normally at the time of release and continued to transmit dive and location data until 17 Sept. 1999, 110 days after capture. The tag package likely detached from the animal at that time.

1 JUNE: Due to fuel supply constraints, only one tide per day could be worked during the last two days of the project. Weather was good for the morning tide and the crew was on the water by 0700 h. However, no whales were located.

2 JUNE: The weather remained clear and the morning tide was chosen for the last capture attempt. A group of about 100 whales was located 2 km up the Little Susitna River. The whale tagged the previous day was seen in the group, swimming normally with the package securely in place. Two beach sets, similar to the one described on 31 May were attempted, but no whales approached the net.

Harvest History of Belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska

BARBARA A. MAHONEY and KIM E. W. SHELDEN

ABSTRACT—Belugas, Delphinapterus leucas, *in Cook Inlet, Alaska, represent a unique and isolated marine mammal population that has been hunted for a variety of purposes since prehistoric times. Archeological studies have shown that both Alutiiq Eskimos and Dena'ina Athabaskan Indians have long utilized many marine resources in Cook Inlet, including belugas. Over the past century, commercial whaling and sport hunting also occurred periodically in Cook Inlet prior to the Marine Mammal Protection Act of 1972 (MMPA). During the 1990's, the hunting mortality by Alaska Natives apparently increased to 40–70 whales per year, which led to the decline of this stock and its subsequent designation in 2000 as depleted under the MMPA. Concerns about the decline of the Cook Inlet stock resulted in a voluntary suspension of the subsistence hunt by Alaska Natives in 1999. The difficulty in obtaining accurate estimates for the harvest of these whales is due to the inability to identify all of the hunters and, in turn, the size of the harvest. Attempts to reconstruct harvest records based on hunters' recollections and interviews from only a few households have been subject to a wide degree of speculation. To adequately monitor the beluga harvest, the National Marine Fisheries Service established marking and reporting regulations in October 1999. These rules require that Alaska Natives who hunt belugas in Cook Inlet must collect the lower left jaw from harvested whales and complete a report that includes date and time of the harvest, coloration of the whale, harvest location, and method of harvest. The MMPA was amended in 2000 to require a cooperative agreement between the National Marine Fisheries Service and Alaska Native organizations before hunting could be resumed.*

Introduction

Belugas, *Delphinapterus leucas*, are distributed throughout Arctic and subarctic waters of the Northern Hemisphere (Hazard, 1988). Belugas in Cook Inlet, Alaska, sometimes range between Yakutat Bay and Shelikof Strait (Fig.1); however, sightings outside of Cook Inlet are infrequent and generally limited to small numbers (Laidre et al., 2000). Due to the absence of sightings south of the Alaska Peninsula (Laidre et al., 2000), their presence year-round in Cook Inlet (Rugh et al., 2000), and evidence of genetic discreteness (O'Corry-Crowe et al., 1997), the belugas found in Cook Inlet appear to be isolated from beluga populations found in western and northern Alaska.

The apparent decline of this stock during the 1990's (Hobbs et al., 2000) has been attributed, in part, to overexploitation by hunters. Subsequently, Cook Inlet belugas were designated in 2000 as depleted under the Marine Mammal Protection Act of 1972 (MMPA) (NMFS, 2000a). This paper reviews and describes beluga use and harvest levels in the Cook Inlet region from prehistory to the present. Included are a summary of current efforts to manage the stock and a description of the steps that NOAA's National Marine Fisheries Service (NMFS) has taken to establish reliable harvest estimates.

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Whaling Prior to the 20th Century

Alutiiq Eskimos and Dena'ina Athabaskan Indians have occupied the coastal areas surrounding Cook Inlet since prehistoric times (de Laguna, 1975). These hunting societies utilized many marine resources including belugas, seals, Otariidae and Phocidae; and porpoises, Phocoenidae. At prehistoric village sites in Kachemak Bay and near West Foreland (Fig. 1), researchers have recovered a few bones that appear to be from belugas (de Laguna, 1975; Lobdell, 1980; Workman et al., 1980). As is the case today, it is likely that blubber and meat were flensed from these whales on shore, near the places of harvest, so the small number of beluga bones in village middens may under represent the magnitude of the harvest (de Laguna, 1975).

Beluga hunters employed several techniques to capture these whales. Some techniques unique to the Dena'ina in Cook Inlet include a hunting platform or "yuyqul" (spearing tree), as well as fences, weirs, and moveable dams made of poles (Fall, 1981; Kari, 1987). Each apparatus was designed to take advantage of seals and belugas that entered streams and rivers on the flood tide. Dams and fences trapped the animals as they attempted to leave the stream or river on the ebb tide (Fall, 1981). A hunter in the "spearing tree" (Fig. 2), usually a spruce tree driven upside-down into the mud of the river at low tide, would harpoon an animal as it swam past during higher tides. The harpoon was fitted with a toggle point and a floating bladder (usually made of sealskin) attached with braided sinew ropes.

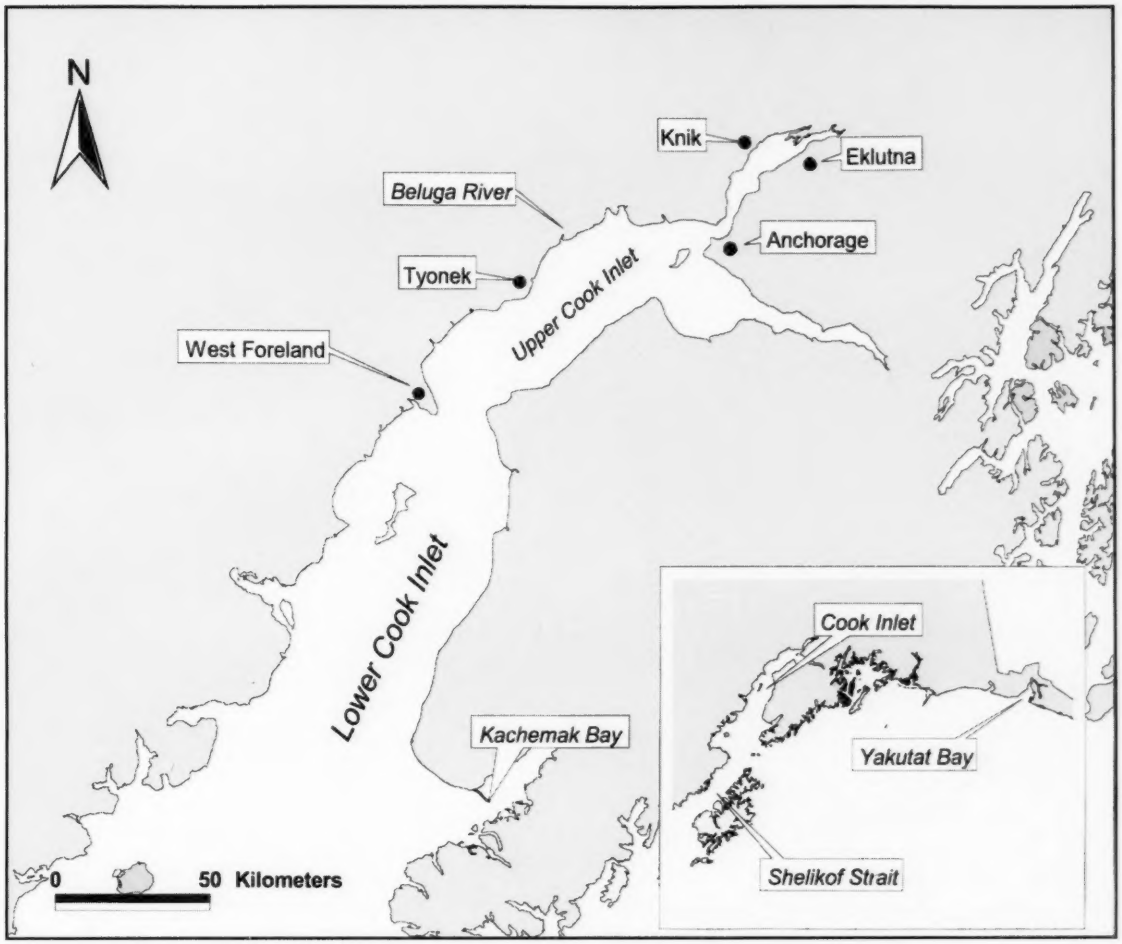

Figure 1.—Cook Inlet and the Gulf of Alaska with place names mentioned in text.

Hunters in kayaks or baidarkas would then pursue the struck whale, subsequently killing it with a lance (Wrangell, 1970). Hunting platforms were still in use in Cook Inlet during the 1830's (Wrangell, 1970).

Wrangel (1989) further described Native beluga harvest and use in the mid 1800's, noting that the women "try out" oil from small fish and belugas which were captured as follows: "The men implant posts in places where beluga go in search of small fish, such as low water close to shore or in streams. The men sit near these posts and watch the fish. As soon as one comes close to a post, the Kenaits will shoot an arrow at the fish, or actually, an arrowhead, which is fastened to a cord 1.5 sazhens long, with a bladder attached to the other end of the cord. The arrow becomes embedded in the beluga, which quickly thrashes off; the bladder shows its location; another fisherman in a baidarka pursues it, grabs the cord, stabs the beluga several times and pushes the dead creature ashore...These activities last until the end of July." The author added that the "Kenaits" called themselves "Tnaina," numbered about 460 families, and "who lived along the shore and in environs of Kenai Bay . . . ."

Whaling in the 20th Century

Dramatic changes took place in the Cook Inlet region during the 20th century. Anchorage grew after the completion of the Alaska Railroad in 1923, during military expansion through the 1940's and 1950's, and with oil and gas development during the 1960's and 1970's (Atwood, 1957; Haycox and Haycox, 1977; Alaska Geographic, 1983, 1996).

While the Dena'ina in Tyonek, on the west side of Cook Inlet, continued small-scale hunts of belugas during the century, the beluga population was also subjected to periodic, large-scale com-

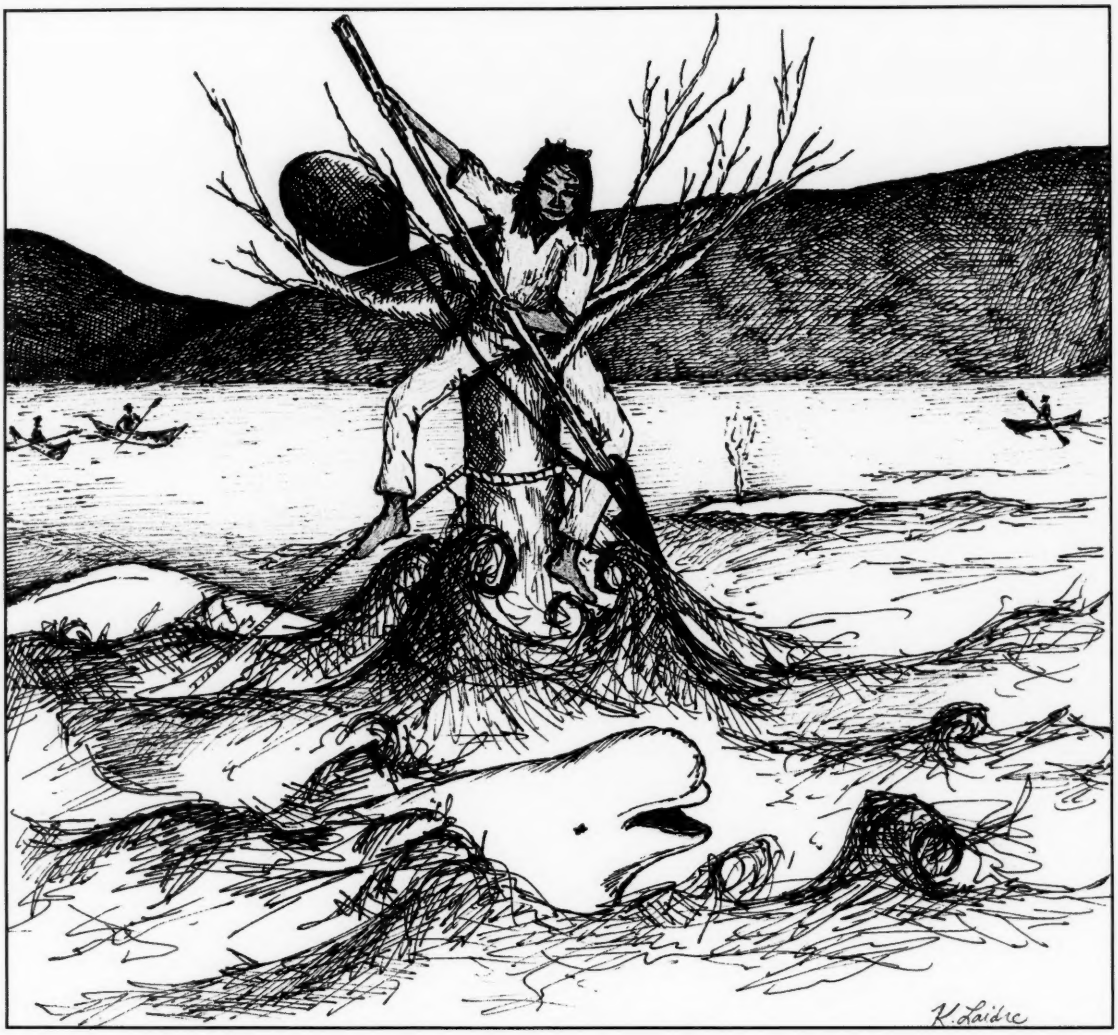

Figure 2.—A "spearing tree" once used by Dena'ina Athabaskans to hunt marine mammals in Cook Inlet, Alaska. Illustration by K. Laidre based on a drawing by L. Savage in Kari (1987).

mercial harvests and smaller harvests by non Native hunters. Many of the beluga hunters from communities outside of Cook Inlet moved to the area during these times of economic growth, either for paid employment (Stanek, 1994) or as part of the military. Demographically, the hunting community in Cook Inlet changed substantially.

Commercial Whaling

Commercial whaling has occurred periodically in Cook Inlet during the last 100 years. The Beluga Whaling Company operated for 5 years at the Beluga River in upper Cook Inlet, where the company harvested 151 belugas (9, 42, 0, and 100 during 1917–20, respectively) before going bankrupt in 1921 (Bower and Aller, 1917, 1918; Bower, 1919, 1920, 1921). Long-time residents interviewed by Alaska Department of Fish and Game (ADFG) personnel recalled a commercial hunt of 100 belugas on the Beluga River in the 1930's (Klinkhart, 1966; Fall et al., 1984; Lowry, 1985; Stanek, 1994); however, no record of this hunt exists in the Alaska fishery and fur-seal industries documents for this time period (Bower, 1931–41).

Beluga products were sold in Anchorage during the 1940's and 1950's by residents of the lower Susitna Basin and the villages of Knik and Eklutna (Stanek, 1994). Some of these products (such as muktuk and meat) were sold to the Alaska Native Medical Center, which opened in 1953, in an effort to

Beluga Offer Top Big Game

Big Game Hunters: prospect of a new quarry is in the offing. The game is the 10 to 20 foot beluga, or white whale.

Several Alaskan guides have said that hunting the beluga whale is by far the most exciting big game hunting ever done.

The Beluga Whale Hunt Club has one and four-day beluga whale hunts available for the season.

The big game sport of beluga hunting begins at sea in an open dory about 20 feet long. Three or four hunters man each dory.

Weapons utilized in each hunt are high powered rifles, Eskimo-style harpoons, and a Norwegian whaling gun.

The dory crew works the boat into a herd, or pod, of whales. A pod can be up to five miles long and contain hundreds of whales.

One whale is cut out of the pod. The dory rides herd on it and edges it toward shallow water.

The whales are hunted in shallow water because of the difficulty of tracking in deep water. In shallow water, the whale can be followed by its foaming wake.

After an hour or more of tracking, with more than 100 rounds of ammunition spent, the whale is usually fatigued enough to allow the dory to come within harpoon-throwing distance.

Hardier hunters use the 10.15-mm Norwegian harpoon rifle, as it really packs a punch.

A float is attached to the harpoon line making any further tracking of the whale an easy matter, even in deeper water.

Once secured, the whale is towed back to camp.

Figure 3.—Advertisement for guided beluga hunts published in "Alaska Outdoors, A Thursday Feature" of the Anchorage Daily Times newspaper (1 July 1965 edition, p. 21).

supply traditional foods to the patients (Stanek, 1994).

Sport Hunting

In the summer of 1963, the Kenai Chamber of Commerce sponsored the organization of The Beluga Whale Hunt Club, in part to attract tourists to the Kenai area. The club advertised beluga hunting as one of the most exciting big game sports in Alaska (Fig. 3). The beluga hunt and subsequent whale barbecue of "beluga-burgers" were featured events at the Kenai Days fair from 1963 through 1965 (reported in the local newspaper, The Kenai Peninsula *Cheechako News*). In 1963, the Chamber offered a $100 prize for the first whale landed at the fair (*Cheechako News*, 1963a). A "practice" whale was harvested on 21 July 1963 at the mouth of the Beluga River (Table 1), and about 150 lb of meat were transported to Kenai with a piece of hide measuring 6 ft × 6 ft. Hunt organizer, John Hulien, reported that "other portions of the whale were too full of bullet holes to make a good hide" (*Cheechako News*, 1963b). In 1964, hunting began 1 May and continued through the Kenai Days fair held in late August. At least two whales (female with calf) were harvested prior to the Kenai Days fair (*Cheechako News*, 1964a) (Table 1). A whaling station was proposed, and attempts were made to develop beluga products such as whale oil soap (*Cheechako News*, 1964b) and canned meat (*Cheechako News*, 1965a). Hunts were not always successful, and at least in one case "about 250 rounds of ammunition [were expended before] the hunters gave up the chase" (*Cheechako News*, 1965a). After 1965, the hunt and barbecue were no longer part of

Table 1.—Records of beluga whales taken in Cook Inlet, Alaska. Multiple entries in a given year are indicative of different sources; the counts are not additive. Number taken represents a minimal estimate of the number of belugas killed unless noted otherwise.

Year	Number taken	Description	Source
1930's to early 1940's	6-7 annually	Tyonek Native subsistence harvest.	Fall et al. (1984)
1940's and 1950's	Unknown	Hunted by trappers and homesteaders in lower Susitna Basin and Natives in Knik and Eklutna; most products sold in Anchorage.	Stanek (1994)
1950's, 1960's and 1970's	"Virtually nil"	Tyonek Natives shifted hunting effort to terrestrial mammals, primarily moose.	Fall et al. (1984); Interagency Task Group (1978)
1963	1	Killed at the Beluga River by members of the Beluga Whale Hunt Club based out of Kenai. Unknown how many whales were injured or killed but lost during this and other hunts undertaken during the summer of 1963.	*Cheechako News* (1963a,b)
1964	2	A female (14 ft, 1,400 lb) and its calf (5 ft) were harvested by members of the Beluga Whale Hunt Club. Number of animals killed or injured but lost is not known for the 1964 hunting season.	*Cheechako News* (1964a,b)
1965	1	At least one kill by members of the Beluga Whale Hunt Club is inferred from a news article on "Beluga-Burgers." About 250 rounds of ammunition were expended during one unsuccessful hunt. Number of animals killed or injured but lost is not known for the 1965 hunting season.	*Cheechako News* (1965a,b)
1979	3	Tyonek Native subsistence harvest.	Fall et al. (1984)
1980	5–7	Most taken incidental to commercial salmon fishing.	Burns and Seaman[1]
1981	1 killed, 4 SL[2]	Tyonek Native subsistence harvest.	Fall et al. (1984)
	3–6	Most taken incidental to commercial salmon fishing.	Burns and Seaman[1]
1982	1 killed, 2 SL	Tyonek Native subsistence harvest.	Fall et al. (1984)
	3–6	One taken by a Tyonek hunter; the rest were taken incidental to commercial salmon fishing.	Burns and Seaman[1]
1983	1	Tyonek Native subsistence harvest.	Fall et al. (1984)
	3–6	Most taken incidental to commercial salmon fishing.	Burns and Seaman[1]
1984–86	No data		
1987	8 killed, 1 SL	Reported from 4 hunting households.	Stanek (1994)
1988	12 killed, 3 SL	Reported from 5 hunting households.	Stanek (1994)
1989	11 killed, 2 SL	Reported from 9 hunting households.	Stanek (1994)
1990	7 killed, 2 SL	Reported from 5 hunting households.	Stanek (1994)
1991	No data	Households not contacted due to lack of research funding.	Stanek (1994)
1992	9 killed, 1 SL	Retrospective estimates from 8 hunting households surveyed in 1993.	Stanek (1994)
1993	13 killed, 4 SL	Reported from 16 hunting households.	Stanek (1994)
	30	This estimate includes the minimum estimate of 17 reported in Stanek (1994) in addition to the number of households not surveyed (3) and hunters not from Cook Inlet (10).	Hill and DeMaster (1998)
1994	19 killed, 2 SL	Reported by P. Blatchford, D. Owens, and R. Stanek to the Alaska and Inuvialuit Beluga Whale Committee (ABWC)	ABWC[3]
1995	60 killed, 14 SL	Harvest records collected by the Cook Inlet Marine Mammal Council (CIMMC) and reported to the ABWC. Tally includes 24 landed, 8 kiiled but lost, and 5 SL between April and June; 26 landed and 9 SL between July and October; and 2 taken by a hunter from Kotzebue.	ABWC[4]
	50 killed, 22 SL	NMFS combined killed but lost with SL and excluded the 2 whales harvested by the Kotzebue hunter in its report.	Hill and DeMaster (1998)
	42 killed, 26 SL	No explanation was provided for why this harvest was revised in the NMFS 1999 stock assessment.	Hill and DeMaster (1999)
1996	49 killed, 49-98 SL	Harvest records collected by the CIMMC and reported to the ABWC. CIMMC representatives (A. Nuglene and D. Alex) believed the reported SL was overestimated.	ABWC[5]
	49 killed, 49-98 SL	NMFS estimated a total take of 123 belugas (range 98-147) based on the reports from the CIMMC.	Hill and DeMaster (1999)
1997	35-75	Reported by CIMMC representative A. Nuglene to the ABWC. Includes estimated number landed (35) and estimated total killed (65-75), but no estimate of SL.	ABWC[6]
	35 killed, 35 SL	NMFS calculated a minimum estimate of 70 belugas taken based on information presented to the ABWC.	Hill and DeMaster (1999)
1998	21 killed, 21 SL	NMFS estimated SL lacking a complete harvest report from CIMMC. Does not include an unverified report of 20 beluga taken in one weekend in June.	Ferrero et al. (2000), NMFS unpubl. data[7]
1999	0	Alaska Natives propose a moratorium on Cook Inlet beluga hunting and suspend the 1999 hunt.	Ferrero et al. (2000)
2000	0	Although a harvest quota of 1 whale was approved for the Native Village of Tyonek, the hunts were not successful.	NMFS unpubl. data

[1] Burns and Seaman, text footnote 1.
[2] SL = struck and lost, not known if the beluga died.
[3] ABWC, text footnote 4.
[4] ABWC, text footnote 5.
[5] ABWC, text footnote 6.
[6] ABWC, text footnote 7.
[7] Data on file at NMFS Alaska Reg. Off., Protected Resour. Manage. Div., Anchorage.

the scheduled Kenai Days fair, and the club's activities were no longer featured in the local paper.

Sport and commercial whale harvests in U.S. waters were banned by the Marine Mammal Protection Act (MMPA) of 1972 (16 U.S.C. 1372 § 102(f)). Only subsistence harvests undertaken by Indians, Aleuts, or Eskimos residing in Alaska or along the coasts of the North Pacific or Arctic Ocean are exempt from all MMPA provisions (except those under § 109, described in the Legislation and Harvest Monitoring section).

Subsistence Whaling

The Dena'ina in Tyonek harvested about 6 or 7 whales per year in the 1930's and early 1940's (Fall et al., 1984). During the 1940's, hunters began to focus their efforts on terrestrial mammals, in particular moose, *Alces alces gigas* (Fall et al., 1984). Interest in beluga hunting renewed during the late 1970's, but data are not available on the number of whales taken between 1940 and 1979 (Table 1). Hazard (1988) suggested that on average 5 whales were harvested per year with an annual total take of 10 (including struck but lost animals). However, this is potentially misleading, as the average was based on subsistence hunting reports from 1980 to 1984 (Burns and Seaman[1]) when the majority of whales were taken incidental to commercial Pacific salmon, *Oncorhyncus* spp., fishing rather than by subsistence hunting (Table 1). And the annual take of 10 was a number proposed as a sustainable harvest level by the Interagency Task Group (1978), rather than the actual harvest, which at that time was reported to be "virtually nil" (Interagency Task Group, 1978). Fall et al. (1984) reported at least 20 Tyonek residents participated in hunts between 1981 and 1983, with at least one beluga retrieved each year (Table 1).

By the end of the 1980's, Alaska Native subsistence hunting had experienced a resurgence. North Slope oil revenue contributed to growth throughout the state during the 1970's and 1980's, firmly establishing Anchorage as a hub of transportation and commerce in Alaska (Alaska Geographic, 1983, 1996; MOA[2]). In 1980, the Alaska Native community numbered roughly 9,000 in Anchorage (about 14% of all Alaska Natives in the state) (MOA[3]). By 1990, the community numbered a little over 14,500, with Eskimos comprising the single largest ethnic group in Anchorage (6,034) followed closely by American Indians (5,985) (MOA[3]). Eight years later the Native population had increased to 20,531, representing 20% of all Alaska Natives in the state (MOA[3]).

Ease of air travel between rural villages and Anchorage since the 1970's (Alaska Geographic, 1983, 1996) has made Cook Inlet accessible to nonlocal beluga hunters. Contemporary beluga hunters in Cook Inlet include: 1) the Dena'ina who continue to hunt belugas near the village of Tyonek; 2) Alaska Natives who have moved to Anchorage, the Matanuska Valley, or Kenai Peninsula from other areas of the state; 3) and Alaska Natives who visit Cook Inlet to hunt and then return to their communities.

Hunting methods have changed dramatically since the mid 1800's. Hunters now approach belugas in shallow water using motor-driven boats; individual whales are singled out from a group, pursued, shot with a high-powered rifle, then gaffed or harpooned and towed to shore by running a rope through the lower mandible or around the tail stock (Fall et al., 1984; Stanek, 1994; Lerczak et al., 2000). The flippers and tail, considered a delicacy by some hunters, are removed first; then the skin and blubber layer (also called muktuk) is cut away (Fig. 4). Sometimes meat is collected as well (usually the backstrap and ribs), and bones and teeth are used for handicrafts (Stanek, 1994).

ADFG Division of Subsistence, with support from the Alaska Beluga Whale Committee (ABWC) and NMFS, initiated a study in 1987 to document subsistence use of belugas in Cook Inlet by Alaska Natives (Stanek, 1994). Several, but not all, hunting households were contacted and interviewed most years between 1987 and 1993 (Table 1). Some belugas were likely taken by hunters who were not surveyed as some of these hunters have since reported active hunting during this time period. Therefore, the harvests reported from 1987 to 1993 were undoubtedly minimal estimates (Stanek, 1994).

In 1994, a group of local hunters in Anchorage joined together to form the Cook Inlet Marine Mammal Council (CIMMC). Although the CIMMC has kept records of ongoing harvest since 1995 (Hill and DeMaster, 1998; ABWC[4,5,6,7]) (Table 1), many Alaska Native hunters in Cook Inlet were not affiliated with CIMMC and did not give them harvest data, thus these estimates were also minimal.

The difficulty in obtaining accurate estimates for the Alaska Native harvest of beluga whales in the Cook Inlet region is due to the inability to identify affiliations of the harvesters and in turn the size of the harvest. In particular, it is difficult to account for those Natives who hunt in Cook Inlet only when visiting relatives or friends in the Anchorage area, or for the one-time experience of hunting from an urban area, or when the hunting season in their area is unproductive (Stanek, 1994). The available information is insufficient to deter-

[1] Burns, J. J., and G. A. Seaman. 1986. Investigations of belukha whales in the coastal waters of western and northern Alaska: II. Biology and ecology. U.S. Dep. Commer., NOAA, Natl. Ocean Serv., Anchorage, Alaska, Final Rep., Res. Unit 612, 129 p.

[2] MOA. 1987. The Municipality of Anchorage, 1982–1987: the growth years. Publication of the Municipality of Anchorage (MOA) available through the Anchorage Municipal Library (Call Number: N 352.07983 ANCHORA).

[3] MOA. 2000. Anchorage indicators 2000. Rep. avail. at Municipality of Anchorage website [http://www.ci.anchorage.ak.us/services/departments/com/research/index.html] accessed March 2001.

[4] ABWC. 1994. Minutes of the Alaska Beluga Whale Committee, 15–16 November, 11 p. Avail. from ABWC, General Delivery, Barrow, AK 99723.

[5] ABWC. 1995. Minutes of the Alaska Beluga Whale Committee, 30 November–1 December, 10 p. Avail. from ABWC, General Delivery, Barrow, AK 99723.

[6] ABWC. 1996. Minutes of the Alaska Beluga Whale Committee, 5–6 December, 13 p. Avail. from ABWC, General Delivery, Barrow, AK 99723.

[7] ABWC. 1997. Minutes of the Alaska Beluga Whale Committee, 20–21 November, 10 p. Avail. from ABWC, General Delivery, Barrow, AK 99723.

mine the precise harvest level changes through time. However, it appears that at least 30 belugas were taken annually by subsistence hunters during the mid- to late-1990's (Table 1), a period in which the population declined (Hobbs et al., 2000).

The harvest levels discussed so far include only the number of belugas landed. They do not reflect the total kill, partially because of the potential for under reporting but also because whales were struck and lost. The struck and lost estimates (Table 1) were not accurate because: 1) surveys within the hunting community have been sporadic, 2) hunters have stated their reluctance to report "struck and lost" whales (CIMMC[8]), 3) surveys have not been conducted until after the hunting season, relying on hunters' memories of multiple events, and 4) some hunters were not known to NMFS or CIMMC and were not included in the surveys.

In the 1990's, hunters have observed increasing numbers of whale carcasses along the west shore of Cook Inlet during the summer months (Huntington, 2000). However, the ratio used to estimate struck and lost (1–2 times the recorded harvest (CIMMC[9])) has been considered by some to be too high for the entire harvest (Table 1).

In 1995, concerns were raised about the sale of Cook Inlet beluga muktuk by Native hunters to local markets (ABWC[5]). While the Marine Mammal Protection Act does prohibit the commercial harvest of whales in U.S. waters, an exemption for Alaska Natives allows the selling of edible portions of marine mammals in Native villages and towns in Alaska (16 U.S.C. 1371 § 101 (b)(2)). One Anchorage retailer estimated selling about 3,000 lb of beluga muktuk annually, roughly equivalent to 15 adult belugas (NMFS, 2000b). By the spring of 1999, concerns about the decline of the Cook Inlet stock and its continued exploitation led to the voluntary suspension of the subsistence hunt by the Native community and to a number of legislative actions.

Figure 4.—Cook Inlet beluga hunters removing muktuk from a female harvested 15 July 1996. Additional information is provided in Table 2.

Legislation and Harvest Monitoring

After reviews, NMFS determined in 1999 that reporting regulations (under MMPA § 109(i)) were necessary to establish reliable beluga harvest estimates (NMFS, 1999a). While NMFS drafted these reporting regulations during the spring and summer of 1999, Alaska Sen. Ted Stevens introduced emergency Federal legislation amending the MMPA to allow hunting during the 1999 and 2000 seasons only if a cooperative agreement was in place between NMFS and Alaska Native organizations (P.L. 106–31 §

[8] CIMMC. 1996. Native harvest and use of beluga in the upper Cook Inlet from July 1 through November 15, 1995, 3 p. Avail. from Alaska Reg. Off., NMFS, 222 West 7th Ave., Anchorage, AK 99513.

[9] CIMMC. 1997. Native harvest and use of beluga in Cook Inlet from April throughout November 1996, 5 p. Avail. from Alaska Reg. Off., NMFS, 222 West 7th Ave., Anchorage, AK 99513.

3022). The legislation was to remain in effect until 1 October 2000.

On 1 October 1999, NMFS published a final rule amending 50 C.F.R. 216.23 to require that Alaska Natives harvesting belugas in Cook Inlet collect the lower left jaw (with teeth intact) and deliver the jaw to the NMFS Anchorage Field Office within 72 h of returning from a hunt (NMFS, 1999b). A complete report from each whaling captain or vessel operator is due within 30 days of the hunt. The reporting forms include the date and time of the harvest, coloration of the whale, harvest location, method of harvest, and other comments such as stomach contents and any unusual physical or behavioral observations. Once obtained by the NMFS Anchorage Field Office, this information is made available to hunters, Alaskan Native organizations, and the public.

Without such a program, NMFS had been able to collect data on harvested animals only opportunistically (Table 2, Fig. 5). The teeth and attached flesh are used to determine the animal's age and sex. Removal of the lower left jawbone also marks and therefore distinguishes carcasses as a subsistence harvest rather than "struck and lost" or death by other causes. In the past, the cause of death of belugas found stranded in Cook Inlet had been difficult to determine (Moore et al., 2000) except where flensing was obvious (Table 2). Without accurate and timely information on the subsistence harvest, NMFS would not be able to execute its Federal mandate to conserve this stock effectively.

On 23 May 2000, NMFS entered into an interim cooperative agreement with CIMMC to comanage the Cook Inlet beluga stock. The interim agreement allowed for the harvest of 1 beluga during 2000, noting that any whale that was struck but lost also counted against this harvest limit. The harvest was allocated to the Native Village of Tyonek by the CIMMC, however, no whale was taken. The agreement expired on 31 December 2000.

On 31 May 2000, one week after entering into the cooperative agreement with CIMMC, NMFS promulgated final regulations designating the Cook Inlet beluga stock as depleted under the MMPA (NMFS, 2000a). With belugas listed under the MMPA, any major Federal action also became subject to the requirements of the National Environmental Policy Act (NEPA). Although the interim cooperative agreement and harvest limit remained valid until 31 December 2000, all subsequent harvest plans now constitute a major Federal action. To meet NEPA requirements, an Environmental Impact Statement (EIS) presenting 6 alternatives for the subsistence harvest was drafted September 2000 (Balsiger[10]). As part of the harvest regulations, NMFS also proposed prohibiting the sale of Cook Inlet beluga products (NMFS, 2000b). A public hearing before an Administrative Law Judge

Table 2.—Data collected on beluga whales harvested by subsistence hunters in Cook Inlet, Alaska, 1992–98. Teeth collected in 1997 and 1998 have not yet been aged.

Date		Sampling location	Vital statistics		
			Sex	Length	Growth layers[1]
1992	4 June	Susitna River, Big Island	?		
	28 Aug.	Susitna River mouth	?		23
1993	30 June	Little Susitna River, upstream	M[2]	141" (358 cm)	34
	1 July	Beluga River	M	150" (381 cm)	
1994	22 July	Susitna River, Big Island	F	10' (305 cm)	
	23 July	Susitna River, Big Island	M	15.5' (472 cm)	
			F	10' (305 cm)	
1995	20 Apr.	Kachemak Bay	F	240 cm	4
	3 May	Susitna River	M	409 cm	22
	9 May	Susitna River, Big Island	F	360 cm	19
	1 June	Susitna River, Big Island	F	353 cm	22
	5 June	Susitna River, East Fork	F[3]	368 cm	28
	19 June	Susitna River	M	422 cm	25
	27 June	Beluga River	M	377 cm	19
	28 June	Beluga River	M	391 cm	18
	11 Aug.	Susitna River, Big Island	M	413 cm	
	13 Sept.	Knik Arm, W. of Eagle River	F[4]	96" (243.8 cm)	
	22 Sept.	Anchorage, E. of Point Woronzof	M	455 cm	28
	13 Oct.	Chickaloon River	M	>10' (305 cm)	
			F	<10' (305 cm)	
1996	18 June	Susitna River, Big Island	F[5]	367 cm	23
	15 July	Susitna River	F[6]	356 cm	22
	29 July	Susitna River, Big Island	F[7]	359 cm	21
	1 Aug.	Susitna River mouth	?	366 cm	17
	29 Aug.	Knik Arm, Point McKenzie	F[8]	377 cm	
	7 Oct.	Chickaloon River, about 1 mile upriver	M	415 cm	
			M	429 cm	19
			M	367 cm	14
1997	27 May	Susitna River, Delta Island	M	450 cm	
	26 June	Anchorage, Ship Creek	M	420 cm	
	27 Aug.	Anchorage, Westchester Lagoon	M[9]	315 cm	
1998	22 Apr.	Susitna River, Big Island	F[10]	320 cm	
	13 May	Susitna River, Delta Island	F[11]	~320 cm	
			M	450 cm	
	16 May	Susitna River, Delta Island	M[12]	433 cm	
	15 June	Susitna River, Big Island	F[13]	350 cm	
	11 Aug.	Fire Island	M[14]	335 cm	
	1 Oct.	Chickaloon River	?		

[1] Usually two growth layers equal one year (IWC, 1980).
[2] Partially digested Pacific salmon, *Oncorhynchus* sp., found in the esophagus.
[3] Pregnant with female fetus (142.5 cm, >100 lbs (45 kg)).
[4] Missing flukes.
[5] Pregnant with small fetus (2.5 cm by 0.5 cm with hind limb buds), multiparous, and lactating.
[6] Multiparous.
[7] Lactating and multiparous.
[8] Apparent lactation, but lab analysis suggests this is a very young primaparous animal.
[9] Struck and lost, recovered 4 bullets.
[10] Pregnant with female fetus (126 cm, 39 kg), multiparous.
[11] Lactating.
[12] Extremely upturned pectoral fins, a sign of old age (Leatherwood et al., 1982).
[13] Lactating.
[14] Missing flukes.

[10] Balsiger, J. W. 2000. Federal actions associated with management and recovery of Cook Inlet beluga whales. Draft Environmental Impact Statement, 88 p., avail. from Alaska Reg. Off., NMFS, P.O. Box 21668, Juneau, AK 99802.

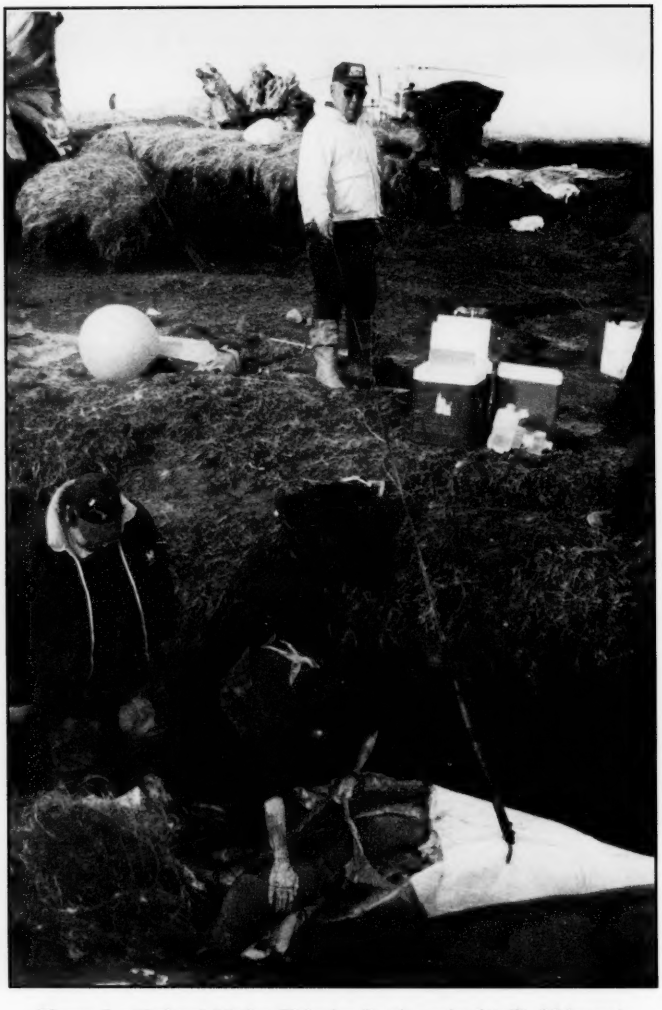

Figure 5.—National Marine Fisheries Service scientist (B. Mahoney), assisted by Cook Inlet beluga hunters, performing a necropsy on a female harvested 22 April 1998. Additional information is provided in Table 2.

was held on 5 December 2000 to determine final regulations for setting harvest quotas (MMPA § 101(b)).

On 15 December 2000, Sen. Stevens introduced legislation removing the 1 October 2000 deadline from Section 3022 in P.L. 106–31, this passed into law on 21 December 2000 (P.L. 106–553). Thus, the taking of a Cook Inlet beluga under the exemption provided in section 101(b) of the MMPA continues to be a violation of the Act unless approved within a cooperative agreement between NMFS and affected Alaska Native organizations (P.L. 106–553).

Concern over the high level of human-caused mortality on this stock of whales has prompted environmental organizations to petition NMFS to list these belugas as endangered under the Endangered Species Act (NMFS, 1999c). However, harvest alone might not have been the only factor behind the decline of this stock. There is evidence of changes in distribution throughout the estuary, as animals are no longer found in areas they once commonly occupied (Rugh et al., 2000; Huntington, 2000), and a large number of habitat questions have yet to be answered (Moore et al., 2000). Regulating the harvest and obtaining accurate counts of the number of animals taken each hunting season will be an important first step towards conserving this unique population of whales.

Acknowledgments

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Traditional Knowledge of the Ecology of Belugas, *Delphinapterus leucas*, in Cook Inlet, Alaska

HENRY P. HUNTINGTON

Introduction

Belugas, *Delphinapterus leucas*, are found throughout the Arctic and are hunted by indigenous peoples in nearly all portions of their range (Kleinenberg et al., 1964). An isolated population is found in Cook Inlet, Alaska (O'Corry-Crowe et al., 1997). Surveys conducted by NOAA's National Marine Fisheries Service (NMFS) indicate a declining trend in the beluga population in Cook Inlet (Hobbs et al., 2000a). There is currently considerable concern about overexploitation of the stock, other possible causes of the decline, the reliability of the population estimates and the trend analysis, impacts to subsistence hunters, and management options for the region (Hill and DeMaster, 1998; CIMMC and RurAL[1]).

Henry P. Huntington (hph@alaska.net) is with Huntington Consulting, 23834 The Clearing Drive, Eagle River, AK 99577. This paper is based on extensive interviews with the hunters of Cook Inlet beluga whales.

ABSTRACT—The population of belugas, Delphinapterus leucas, *in Cook Inlet, Alaska, is geographically isolated and appears to be declining. Conservation efforts require appropriate information about population levels and trends, feeding and behavior, reproduction, and natural and anthropogenic impacts. This study documents traditional ecological knowledge of the Alaska Native hunters of belugas in Cook Inlet to add information from this critical source. Traditional knowledge about belugas has been documented elsewhere by the author, and the same methods were used in Cook Inlet to systematically gather information concerning knowledge of the natural history of this beluga population and its habitat. The hunters' knowledge is largely consistent with what is known from previous research, and it extends the published descriptions of the ecology of beluga whales in Cook Inlet. Making this information available and involving the hunters to a greater extent in research and management are important contributions to the conservation of Cook Inlet belugas.*

This study systematically documents the knowledge of hunters of Cook Inlet belugas and adds to the information available on the population. Similar studies have been done elsewhere in Alaska (Huntington et al., 1999), in Russia (Mymrin et al., 1999), in Canada (Kilabuck, 1998), and in Greenland (Thomsen, 1993). The participation of beluga hunters, including the appropriate use of their traditional knowledge, has been found useful in management in Alaska and Canada (Adams et al., 1993; Richard and Pike, 1993).

In the case of Cook Inlet, relatively little has been published concerning beluga ecology (Hazard, 1988; Moore et al.[2]). In response to concerns about the population trend, the NMFS has conducted aerial surveys and other investigations (Rugh et al., 2000; Hobbs et al., 2000b; Moore et al., 2000). This study adds ecological detail as well as giving insight into the perspective of the hunters of Cook Inlet belugas regarding the ecology of the animals they hunt. The information gathered from hunters is presented in the sections on "Distribution, Abundance, and Migration" and "Natural History." The "Discussion" section reviews the hunters' information in the context of published literature concerning belugas in Cook Inlet and elsewhere.

This study covers the area of upper Cook Inlet, from the Kenai River northward (Fig. 1). This is the area in which the participants hunt. Cook Inlet belugas are seen in the lower inlet at certain times of the year, but little information about that region was gathered in this study. Within upper Cook Inlet, little hunting takes place in Turnagain Arm due to the strength of tidal currents and winds, and so most of the information is centered on the region from the Kenai River across the inlet to Trading Bay and north to Knik Arm and Chickaloon Bay (Fig. 1).

Methods

I used the semi-directive interview to gather information from the participants (Nakashima and Murray, 1988; Nakashima, 1990) (a full discussion of this method is given in Huntington, 1998). It uses open-ended questions to start a conversation in which the topics selected by the researcher are covered, but the order of the topics and the discussion of the relationships among them are chosen by the participant. In addition, the open-ended format seeks a more comprehensive approach to the subject by allowing the participant to address factors and interactions that the researcher might not have anticipated in the list of topics. The initial interviews

[1] CIMMC and RurAL (Cook Inlet Marine Mammal Council and Rural Alaska Community Action Program). 1999. Summary report on the Symposium Forum on the Conservation and Sustainable Use of Cook Inlet Beluga, Anchorage, Alaska, March 10–11, 1999. On file at Cook Inlet Marine Mammal Council, P.O. Box 102456, Anchorage, AK 99510.

[2] Moore, S. E., D. J. Rugh, K. E. W. Shelden, B. A. Mahoney, and R. C. Hobbs. In prep. Synthesis of available information on the Cook Inlet stock of beluga whales. NMFS Alaska Fish. Sci. Cent. Proc. Rep.

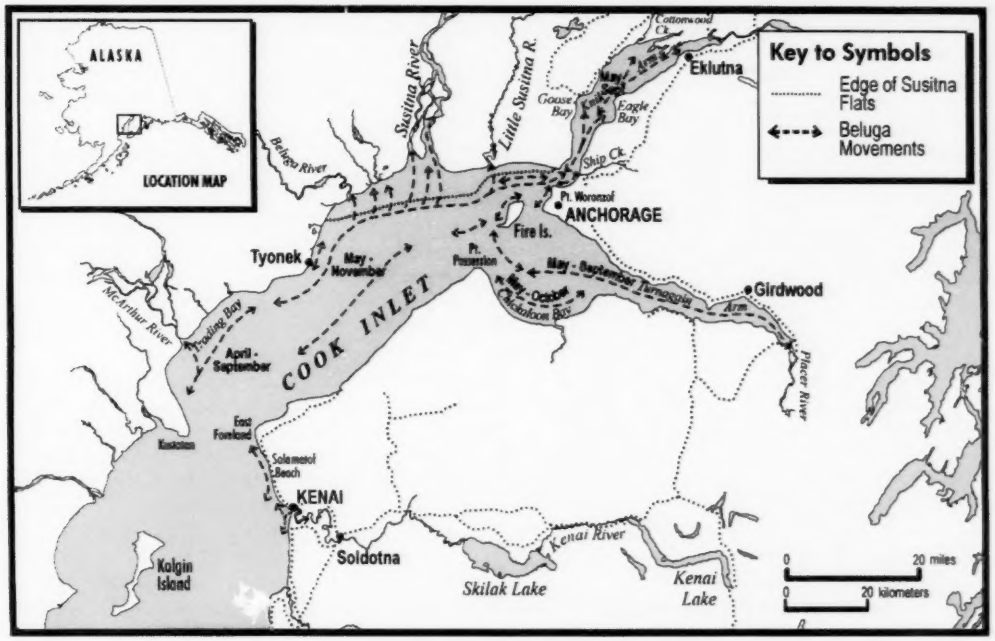

Figure 1.—Beluga movements in upper Cook Inlet, Alaska.

were held between November 1998 and February 1999.

Once the initial interviews were completed, I prepared a draft report with maps and circulated this to the participants and to others knowledgeable about belugas in Cook Inlet for review and comment. I then contacted each of the participants to go over the draft in as much detail as was necessary to ensure that the information described was accurate, complete, and not likely to harm the interests of beluga hunters. This process is in accordance with Federally established ethical principles for research (Interagency Arctic Research Policy Committee, 1992). The review stage took place in February 1999, and a final report was presented at a meeting concerning Cook Inlet belugas in Anchorage, Alaska, 10–11 March 1999.[1]

The participants in the project were Percy Blatchford, Harold and Rachel Dimmick, Clyde Eben, Carl Jack, Fred Mamaloff, Roswell Schaeffer, Lenwood Saccheus, and two hunters who wished to remain anonymous. Participants were identified in cooperation with the Cook Inlet Marine Mammal Council, the Alaska Beluga Whale Committee, and the NMFS, and they were selected on the basis of their experience in the region and their willingness to take part in the study.

Time constraints prevented the inclusion of more hunters, but comments I have received from several other hunters on the final report indicate that little additional information is likely to have been gathered in subsequent interviews. Thus, while further studies may be useful, I am reasonably confident that the information contained in this paper is an accurate reflection of the knowledge of Cook Inlet beluga whale hunters. None of the hunters who participated in the study or reviewed the final report indicated disagreement with the contents of that report, which is the basis for the results given in the next section.

Traditional Knowledge

Distribution, Abundance, and Migration

Between April and November, beluga whales may be found in the upper part of Cook Inlet, north of the Kenai River and Kustatan (Fig. 1). Small numbers of belugas may appear as early as mid April. More typically, they arrive in late April, following the run of lake whitefish, *Coregonus clupeaformis*. While in the upper inlet, the belugas' movements are associated with fish and tide. They follow the fish into the area and feed on successive runs (as described in detail below). Their daily movements follow the ebb and flow of the tide and can be affected by severe weather.

In the Kenai River area, belugas are present from April to November. In the 1930's, belugas would come up the river in groups of up to 50 animals, including calves, chasing fish. Belugas still come up the Kenai River in this way, though the numbers of animals seems to have decreased over the decades, perhaps in response to the increase in human activity in the area. Belugas have been seen off Salamatof Beach, north of Kenai, in March. The animals in this group were all white[3], and were feeding on Pacific

[3] Neonate belugas are dark gray. As they age, their skin lightens progressively, becoming white at maturity, or 5–8 years.

herring, *Clupea pallasi*, or looking for fish, scouting for the rest of the belugas. There were many belugas in the group, but not as many as are seen in May.

In Trading Bay, up until 10–15 years ago, there were great numbers of belugas in June and July (a quantitative estimate of the numbers was not given by the hunters). They would often be found going up the McArthur River in groups large enough that boaters had to be careful not to hit them. Today, only a few are seen in the area. By Tyonek and in the flats by Beluga River, belugas arrive in late April, following the whitefish and then the eulachon, *Thaleichthys pacificus* (also known as hooligan or candlefish), and Pacific salmon, *Oncorhynchus* spp. Belugas go up Beluga River, which is shallow with a rocky bottom, and there are reports of them going as far as Beluga Lake over 30 mi (50 km) upstream. Fewer belugas are seen now in the Beluga River area. Formerly, only white belugas would be seen here, but recently gray ones are seen occasionally, too. Belugas will also go up the smaller creeks and rivers between Beluga River and the Susitna River, feeding on hooligan and king or chinook salmon, *O. tshawytscha*, during high tide when the water in the channels is deep. Belugas are also seen in the area near Tyonek in November, feeding on tomcod, *Microgadus proximus*.

Along the Susitna Flats, belugas are present beginning in late April or early May, and stay throughout the summer. They are typically found in large groups, perhaps 100–200 animals, mixed white and gray. The majority of belugas currently in the upper inlet are in this area, but at times when there are no fish here, such as between fish runs or in years of poor fish returns, the belugas will be elsewhere, often in Chickaloon Bay. They have been seen in the area until November, even when the sea ice is forming. Once in this area, they follow the tide in and out across the flats and into the Susitna River.

Once the tide begins to ebb, the belugas head right for deeper water, rarely getting stranded by accident. In the east channel, they will go upstream as far as the powerline about 5 mi (8 km) from the mouth and beyond on a spring tide, on occasion as far as 30–40 mi (50–65 km) upstream, beyond the influence of the tide. They will also go up the west channel, but not as far as the powerline. The channels in this area are constantly changing, and the ones used by belugas will depend on the configuration in a given year.

If there are many belugas in the area, not all will go upriver. Some will remain at the mouth, feeding there. At low tide, the belugas gather at the edge of the flats in the deeper water or swim farther down the inlet. Along the edge of the flats, they feed on the salmon that are waiting to go upstream with the tide. Belugas will block the entrances to the channels through the flats in order to catch the salmon. Groups of gray belugas, with no white ones, have been seen off the mouth of the Susitna River, in an area where belugas have also been seen stranded in groups of up to 200 animals.

The Little Susitna River has a distinct channel, and some belugas may enter it even at low tide. Solitary large male belugas are sometimes seen along the edge of the flats between the Little Susitna River and Knik Arm and to the southwest of Point Woronzof, moving back and forth with the tide.

In Knik Arm, belugas arrive in early May and remain all summer, moving in and out with the tide. They tend to come in greater numbers later in the summer, moving from the Susitna Flats area over to Knik Arm. They gather in Eagle Bay and elsewhere on the east side of the arm, and sometimes in Goose Bay on the west side at low tide. Few belugas go as far as the upper end of the arm, though some females and calves use the area. Belugas are also seen by the mouth of Ship Creek when there are fish there and on the west side of Fire Island, but not on the east side of Fire Island.

In Chickaloon Bay, belugas are present all summer, but they are most plentiful in this area in the fall when silver or coho salmon, *O. kisutch*, runs attract them to the area. There are few other fish runs in Chickaloon Bay to attract large numbers of belugas for extended periods of time. They will swim up the Chickaloon River to the place a few kilometers upstream where the river narrows sharply. Sometimes during the summer, belugas are found in Chickaloon Bay rather than in the Susitna Flats area, probably due to fish distribution. Chickaloon Bay is very shallow, so the belugas move in and out with the tide.

Belugas will travel to the upper end of Turnagain Arm, after hooligan in May and silver salmon in fall. They will travel past the Seward Highway bridge over the Placer River. Hunters do not go into Turnagain Arm due to its strong winds and currents.

During storms, belugas will go south of Tyonek to await better weather. The inlet can get very rough even in 15–25 mi/h (25–40 km/h) winds. Groups of mixed white and gray belugas have been seen gathered at Fire Island Shoal at low tide in rough water.

In addition to their detailed knowledge of the upper inlet, some hunters had seen belugas in Kachemak Bay and other parts of the lower inlet. In late March, small groups of belugas may be seen in the Fox River flats area at the head of the Bay. Once, a young beluga < 2.5 m long (< 1 yr old) was seen by itself in the mouth of the Fox River. Belugas are also seen in larger groups along the northwest shore of Muddy Bay. A few belugas may be present in Kachemak Bay all summer. Belugas are also found at the mouths of rivers in the lower inlet, along both shores, wherever there are fish to eat. Some may stay in the deeper water of the lower inlet throughout the year.

Where belugas go during winter is unknown, and is a topic of great interest to the hunters. Whether they migrate to the lower inlet, into the Gulf of Alaska, or beyond is a significant question. Belugas are seen occasionally as far away as Yakutat in the eastern Gulf of Alaska and may also be seen in Kodiak. It is not clear whether these animals are part of the population that summers in Cook Inlet, whether these areas are part of the regular migratory route, or whether the animals have strayed far from their usual waters.

The distribution and abundance of belugas in upper Cook Inlet have changed in the past several years. For example, in 1998, the fish runs were early and

small, and belugas were seen in the Anchorage area in April. The belugas were not found as they usually are by the mouth of the Susitna River, but were by the mouth of the Little Susitna and in Knik Arm. This may be a result of changes in fish numbers and patterns, or it may be caused by hunting pressure in the Susitna River area.

Some of these changes may be a continuation of long-term changes that began as early as 1950, perhaps in response to greater levels of human activity in the area. But the majority of the changes are more recent and due in part to substantial changes in the fish runs that draw belugas to upper Cook Inlet. In addition to changes in the distribution of belugas, some hunters note that fewer belugas have appeared in the upper inlet in recent years. Overhunting may be a factor, and some hunters note an increase in the number of struck-and-lost belugas washing up on shore in summer, particularly on the west side of the inlet. The specific details of hunting, other causes of mortality, and changes in the timing and size of fish runs require more attention to come to a common understanding of the various factors affecting belugas in upper Cook Inlet.

Natural History

In the Kenai River, tomcod arrive in February and are present until the end of summer. Herring come to the area in late April and early May. King salmon usually appear in May, but have been known to arrive in late April. They are rarely present after late June. Hooligan arrive at roughly the same time as herring and king salmon. Towards the end of the king salmon run, the first run of red or sockeye salmon, *O. nerka*, begins in late May and early June. These red salmon are locally known as "blueblacks," and are followed by a second run of darker red salmon, which the hunters call "sockeye," in the first half of July. After the sockeye runs, humpback or pink salmon, *O. gorbuscha*, and then silver salmon enter the river. The main run of silver salmon is in later July and early August, but they are present in the river through late November, attracting bald eagles, *Haliaeetus leucocephalus*, to the river in late fall. Few dog or chum salmon, *O. keta*, are found in the Kenai River. They arrive from the west side of the inlet in mid July when they are seen. In mid winter, there are "sucker fish," *Catostomus* spp., in the river. The numbers of all fish in the river have been declining, however, as they have throughout the inlet. The timing and structure of the various runs may have changed, too, over the past several decades.

Belugas come up the Kenai River with the salmon, especially the red salmon. They enter with the flooding tide and stay as long as there are fish. They may be in the area from April to October. The whales go as far up the river as Eagle Rock, about 5 mi (8 km) from the mouth. Belugas will eat any fish they can, including starry flounder, *Platichthys stellatus*. Once a beluga was found thrashing around in shallow water with a flounder stuck in its throat. In the 1930's and 1940's, when fish traps were used near the mouth of the Kenai River, beluga would occasionally be caught in them. (When this happened, the cannery workers would give the beluga to local Native families to use.) During the fish runs, large numbers of belugas would be seen near the mouth of the river, their blows stretching out into the inlet.

The waters of the creeks and sloughs along the lower part of the Kenai River are now browner than they used to be. The discoloration is the result of more beaver, *Castor canadensis*, in the area, which submerge more alder limbs and leaves in the water for winter food. Whether this change has any impact on the fish or the belugas is not clear.

Belugas arrive in the upper inlet with the first runs of fish. First to appear are whitefish in late April or early May, followed by hooligan in great numbers. Shortly after the hooligan arrive, king salmon start going up rivers to spawn, in May. After the king salmon come red salmon, pink salmon, and dog salmon. Silver salmon remain in the area until November, and there are reports of silver salmon in rivers in January. Belugas also feed on a variety of other fish in the inlet and in the rivers, including "lingcod" or burbot, *Lota lota*; steelhead trout, *Oncorhynchus mykiss*; whitefish; northern pike, *Esox lucius*; and Arctic grayling, *Thymallus arcticus*.

Belugas feed intensively, especially on hooligan and salmon. When feeding on hooligan, the belugas are often in a frenzy and will chase the fish up dead-end channels where they are trapped and the belugas can gorge on them. Belugas have been observed chasing salmon, as they zero in on one fish from up to 200 yd (183 m) away.

Belugas swallow fish whole, and 4 ft (1.3 m) long king salmon have been found in their stomachs. On one occasion, 19 king salmon were found in the stomach of an 18 ft (5.5 m) beluga. Another hunter found 9 king salmon in the stomach of a beluga.

Summer feeding is very important to Cook Inlet belugas. When they arrive in the upper inlet in spring, the belugas are thin and sink easily. Their skin is thin, and their blubber is only about 2–3 in (5–8) cm thick. By fall, belugas may have blubber up to 1 ft (30 cm) thick.

Predation by killer whales, *Orcinus orca*, appears to be uncommon. Killer whales are rarely seen near belugas, though they will eat them on occasion when hungry. Belugas avoid killer whales whenever possible. Belugas will stay in Knik Arm even at low tide if killer whales are in the area around Fire Island. Killer whales have been seen chasing belugas to the southwest of Point Possession. When they are in the upper inlet, killer whales are usually found along the tide rip that extends from the north of Fire Island across towards Tyonek then south through the channel between Kustatan and the East Foreland. On rare occasions, killer whales have been seen at the mouth of the Susitna River. Killer whales are occasionally seen in Turnagain Arm, as far up as Girdwood. Killer whales are also seen in the lower inlet, outside Kachemak Bay.

Belugas calve from April through August. Their calving areas include the northern side of Kachemak Bay in April and May, the areas off the mouths of the Beluga and Susitna Rivers in May, and Chickaloon Bay and Turnagain Arm during the summer (Fig. 2). Belugas with near-term fetuses have been caught in the Susitna Flats in May, and dark-

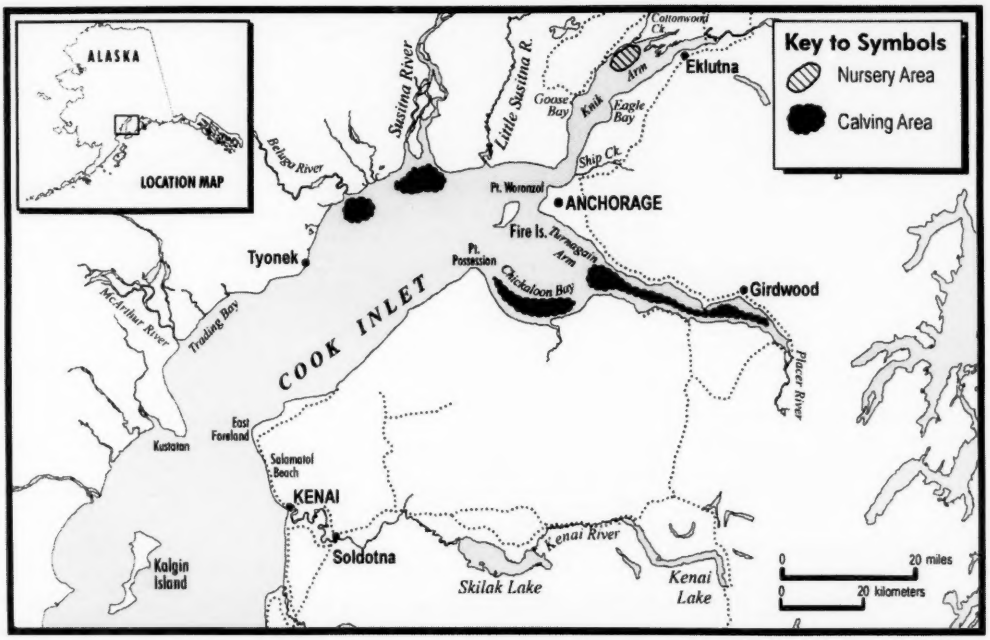

Figure 2.—Beluga calving and nursery areas in upper Cook Inlet, Alaska.

skinned newborn belugas are seen in the area, usually in May though also at other times during the summer. Belugas are sometimes seen with their heads straight up out of the water, and these are thought to be cows giving birth. Cows with newborn calves are sometimes seen in deep water in the upper part of Knik Arm, near Cottonwood Creek, using the sheltered area as a nursery.

Beluga cows and calves are very close. A calf will accompany its mother at all times, and can be seen riding in the eddy on the back of the mother, being drawn along with little effort. Usually, a cow gives birth to a single calf, but twins are seen occasionally.

Today, there are few white (fully mature) adult belugas left in the inlet. The majority of whales are gray (young), and as a result the belugas are becoming sexually mature while still gray, so that gray cows with gray calves are sometimes seen. Hunters regarded this as abnormal, a recent response to changes in the population structure.

Cook Inlet belugas are distinct from other stocks, the largest being larger than belugas found elsewhere, due primarily to better food in the inlet. There are four types of belugas in the inlet, distinguished by size and other characteristics. One type is particularly large, up to 20 ft (6 m) long. There is also a small variety, of which the adults are only 7–8 ft (2.1–2.5) m long. Their age is shown by the wear on their teeth, and they are fast swimmers. The two other types are of intermediate sizes.

The large belugas are sometimes seen at the edge of the deep water off the Susitna Flats in May. They do not enter the channels like the smaller belugas. The large ones have a black stripe at the edge of their flukes that is visible from a distance. Other belugas have a thin stripe, but it is only visible once the beluga has been caught.

Belugas tend to associate in family groups. Groups of mixed white and gray belugas are families traveling together.

Belugas can surface with only their blowhole above the surface, so that they cannot be seen from above the water. They often do this when they are being hunted.

Belugas may lie on the bottom for an extended period at certain times. They can often be found doing this in 2.5 m of water, off the edge of the Susitna Flats at low tide. They will wait for boats to go by, but when disturbed they will surface together and make the water boil with all their activity.

In the Kenai River area, the increase in human activity may have affected beluga distribution and abundance in the river and the nearby waters of the inlet. This activity includes development on the shore, increases in fishing and recreational boating, and airplane takeoffs and landings. The decline in fish in the area is another possible cause of these changes. When feeding in the river, belugas are not afraid of people. In the 1930's, belugas coming up the river after fish would race with boats powered with a 9-horsepower outboard. The belugas were faster. They never attempted to flip or otherwise harm a boat, though on occasion they bumped into a fishing dory in the river.

Belugas have become warier of hunters, but can still be caught when they are busy feeding in the shallows and ignore the hunters' approach. In the Susitna River area, belugas have been seen fol-

lowing boats, even when the outboard is running. Female belugas in the Susitna River have gotten used to one hunter who does not hunt females, and so they do not flee at his approach, though they will flee from other boats. When hunted, belugas will dive and swim away. At other times, they will approach people who are fishing or just sitting in their boats. How they can tell when people are going to hunt them is not known.

When one beluga is being chased, it may use a second whale as a decoy, swimming past the second whale to make it more difficult to follow. On one occasion, hunters began chasing a white beluga, but soon noticed they were chasing a gray beluga, because the white one had successfully used it as a decoy. This behavior has also been noticed as an attempt to divert attention from a cow and calf pair. Before the hunters realized they were following a cow and calf and turned away, another beluga attempted to draw the hunters away by swimming near the cow and calf and then going in another direction while breathing so it could be seen.

Related Observations

The number of fish in Cook Inlet has declined over the past few decades, with sharp declines the past few years. Changes in the abundance of fish and other aspects of the food chain is a major factor in changes of beluga distribution and abundance in the inlet.

Fish in the upper inlet in the summer of 1998 had a number of deformities, including sores on their lips, face, and head, as well as crooked spines.

More and more garbage is washing up on beaches around the inlet. There is also more foam along the water's edge, and along the flats there is a bad smell that has gotten worse in recent years. There is concern about the effluent from oil rigs in Cook Inlet, as well as pollution from other sources in the area, which may be affecting the health of the fish and other inhabitants of the inlet.

Discussion

The information gathered from hunters is largely consistent with published reports (Calkins, 1983; Fall et al., 1984; Hobbs et al., 2000a, b; Rugh et al., 2000; Moore et al.[2]). Fall et al. (1984) derived at least some of their information from interviews with hunters in the village of Tyonek, and so the overlap is not surprising. While the geographic scope of the results above is more limited than the scope of aerial surveys and other research covering the entire inlet, the description of the ecology of belugas for the region of the upper inlet familiar to hunters adds considerable detail to certain aspects of natural history.

The stated arrival of belugas in the upper inlet in mid April extends the observations of Fall et al. (1984) and Hazard (1988), who reported that belugas arrive in the area in May. It is possible that this represents a change in the past decade, as the participants noted that the timing of fish runs has changed over time. Movements of belugas in the upper inlet as reported by hunters appear largely consistent with aerial observations, although the reliability of patterns such as the gradual shift from the Susitna Flats into Knik Arm from May through the summer may not be reflected in aerial survey data.

Beluga use of estuaries and rivers elsewhere is well documented (Smith et al., 1990), and some researchers have attributed this behavior to feeding (Sergeant, 1973; Watts and Draper, 1988; Huntington et al., 1999). In Cook Inlet, Calkins (1983), Hazard (1988), and Moore et al. (2000) report that belugas frequent estuaries and rivers in Cook Inlet, where prey availability is likely to be high. Descriptions of the extent of beluga use of rivers gathered in this study go further than those available previously.

There are also few descriptions of beluga feeding behavior in Cook Inlet in the published literature. Calkins (1983) observed that when belugas are feeding they are aligned randomly relative to one another. Huntington et al. (1999) and Mymrin et al. (1999) reported similar feeding behavior in the Bering and Chukchi Seas. Cooperation among belugas to block the channel through the Susitna Flats and to drive fish into dead-end sloughs have not been reported for Cook Inlet, though Mymrin et al. (1999) reported belugas driving prey to shore in Chukotka, Russia.

Beluga prey have been reported in some detail in other regions (Kleinenberg et al., 1964; Seaman et al., 1982). Reports for Cook Inlet have noted the fish available in various areas of the inlet during different seasons (Calkins, 1983; Fall et al., 1984; Hazard, 1988), but few direct observations of feeding and stomach contents have been reported. The results above attribute greater significance to summer feeding for Cook Inlet belugas than has been noted elsewhere.

Reports of calving in Cook Inlet in April contradict Calkins (1983) who observed no calves during aerial surveys in mid June. A calving period from April to August is consistent with that reported for other stocks of belugas (Burns and Seaman, 1986; Hazard, 1988). Distribution of calving over time and visibility of calves in turbid water are factors that may help explain the apparent discrepancies.

Beluga response to noise has been documented extensively in other areas. Stewart et al. (1983) and Richardson et al. (1995) reported varying degrees of habituation and avoidance, apparently correlated to the absence or presence of hunting and noise associated with hunting. Huntington et al. (1999) and Mymrin et al. (1999) reported similar findings. Thus, the responses in Cook Inlet, ranging from full avoidance to apparently full habituation are consistent with reports from other areas. Attempts to distract or misdirect a pursuing hunter, as reported above, also appear not to have been reported previously.

Sergeant and Brodie (1969) reported that belugas most often attain the largest average sizes for a stock at the southern end of their range, and they attributed differences in size to marine productivity. Several of the participants in this study have hunted belugas elsewhere in Alaska, and they were able to confirm that belugas in Cook Inlet attain the largest size of belugas in the state. Reports of other morphotypes, including very small belugas, suggest a need for further investigation of the morphometrics and growth rates of belugas in Cook Inlet to determine if in fact there are distinct subpopulations with distinctive characteristics.

In addition to adding considerable detail to available information about belugas in Cook Inlet, the participants in this study were able to provide information from the 1930's to the present, a far greater temporal span than exists in the published literature. Changes over time in beluga populations and distribution, in the size and timing of fish runs, and other significant factors affecting belugas are important to document as conservation measures are developed for the region. While confirmation of data on population size and trends is an urgent research priority, attention must also be given to the ecology of Cook Inlet and the potential effects of other factors on the health of the beluga stock. The involvement of hunters and their knowledge is an important step in understanding the belugas of Cook Inlet and in conserving them for future generations.

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Editorial Guidelines for the *Marine Fisheries Review*

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Preferred paper length ranges from 4 to 12 printed pages (about 10-40 manuscript pages), although shorter and longer papers are sometimes accepted. Papers are normally printed within 4-6 months of acceptance. Publication is hastened when manuscripts conform to the following recommended guidelines.

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